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MEASURED FLOW IN ST. VINCENT AND GRENADA PASSAGES IN 1977.(U)
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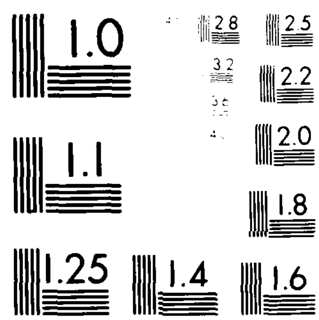

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Naval Ocean Research
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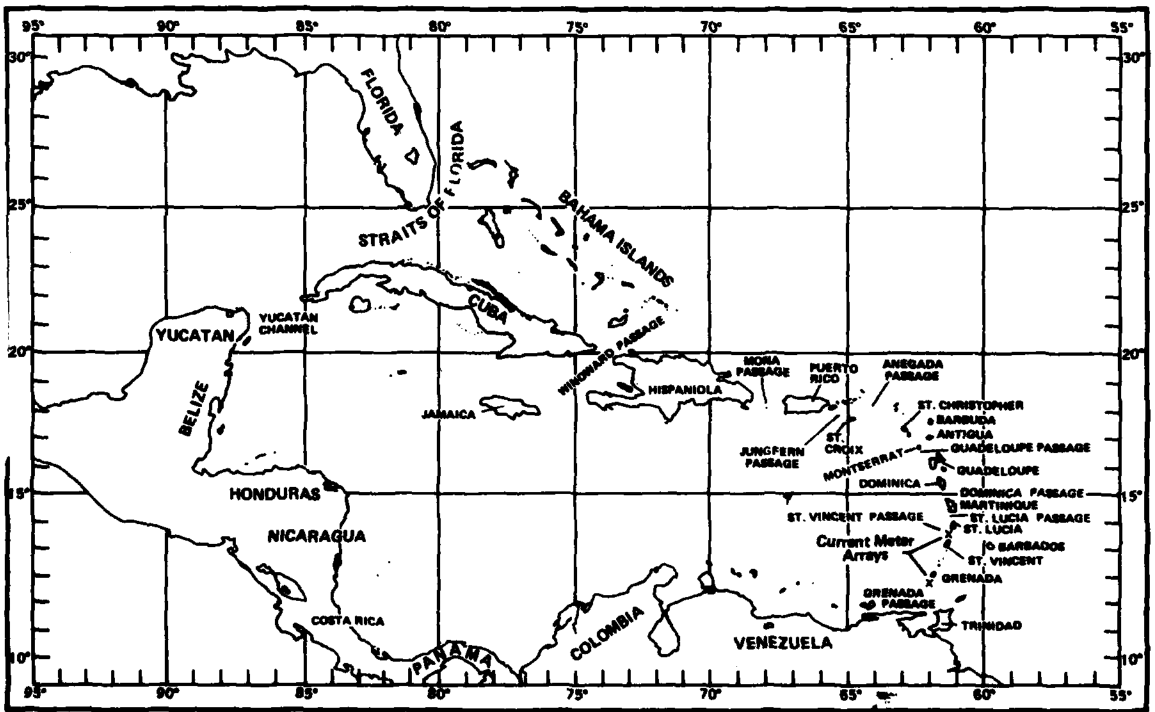
Measured Flow in St. Vincent and Grenada Passages in 1977



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ABSTRACT

Between January and November 1977 flow was measured with ten current meters in St. Vincent and Grenada Passages. Mean scalar speeds exceeded 23 cm/sec at all instruments and flow was predominantly westward. Subinertial variability calculated using wide band (0.0156 CPH) spectral estimates was large, amounting to 14%-77% of the individual record variances. All records showed changes in low frequency flow, such as abrupt changes in direction, stagnation (period of low flow), or 360° rotations in direction. Spectra showed peaks near 12-13 days in near-bottom records from St. Vincent passage, and peaks between 20 and 70 days in the other records.

Strong tidal signals were also found in the velocity records. Between 15% and 74% of the individual record variances were in diurnal, semidiurnal, or harmonic frequency bands. The semidiurnal frequency band contained from 11% - 67% of the record variances. Tidal harmonics were also clearly evident, especially at the two near-bottom instruments deployed sequentially in St. Vincent Passage, where the first five harmonics of the semidiurnal frequency accounted for 27% - 35% of the variance.

Each instrument recorded temperature, and most of the individual record variance was either subinertial (8% - 86%) or semidiurnal (4% - 82%). Together, these frequency bands accounted for 69% of the variance. Tidal harmonics accounted for 2% - 25% of the temperature variance.

ACKNOWLEDGMENTS

We wish to acknowledge the successful deployment and retrieval of current meter arrays by Louis A. Banchero. Captain John W. Arens and the crew of USNS BARTLETT provided at-sea support.

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I. INTRODUCTION

The circulations of the subtropical North Atlantic, the Caribbean Sea, and the Gulf of Mexico are highly interrelated. The net mass inflow into the Caribbean through various passages must balance the net outflow through the Yucatan Channel. The water balance which occurs in the Gulf of Mexico is relatively simple, since there is one channel for net inflow (Yucatan Channel) and one channel for net outflow (Straits of Florida). The Caribbean portion of this coupled system is more complex, since many passages have considerable variability of inflow and outflow (Fig. 1). The factors causing fluctuations of transport are little known and patterns of variability are only scantily explored. Simultaneous meteorological, hydrographic, and current meter data obtained continuously over several years throughout the Caribbean and all passages, are required for a comprehensive understanding of this system. The technical and financial difficulties in obtaining such synoptic data, however, are obvious. The results of the investigation presented in this study include only two of the southernmost Lesser Antilles passages, which may carry a high percentage of the net inflow from the Atlantic.

The current meter data were obtained during January-November 1977 in St. Vincent and Grenada Passages. Locations of the current meter arrays, depths of current meters, durations of records, and other information are shown in Figure 1 and Table 1.

All current meters were AMF Mod 610 Vector Averaging Current Meters, which recorded speed, direction, and temperature averaged over 15 minutes. Specifications of resolution, range, and accuracy of the current meters are described in the manufacturer's manual (AMF Electrical Products Development Division, 1973). The current meter arrays were taut line moorings similar to the mooring described and illustrated by Banchero (1973). Bottom depth, before anchoring the arrays, was carefully explored by about ten crisscrossings of each channel, and vertical accuracy is estimated as 10-12 m.

The purpose of this investigation was to obtain flow characteristics during the entire period of the current meter's operational capability (approximately nine months). The results, besides amplifying knowledge of flow patterns and variability, are applicable also for rudimentary modeling and for guiding further investigations. Although the observations extended over two main seasons (winter and summer), the seasonal variability cannot be interpreted with only nine months of data. Nevertheless, some seasonal differences in flow regimes appeared. The main emphasis was to obtain long, continuous records for estimating variability at frequencies higher than seasonal. In addition, the current meter arrays were deployed at the beginning of a hydrographic survey in the passages and adjacent waters extending between the southern Lesser Antilles and Tobago-Barbados longitudes in January-February 1977. The results of this survey (Mazeika et al., 1980) show a complex mesoscale circulation just east of the southern Lesser Antilles.

II. HISTORICAL FLOW MEASUREMENTS IN THE PASSAGES

Previous current measurements taken in the Lesser Antilles and in some of the northern Caribbean passages have provided important information. They can be compared with the variability in other areas of this system and may eventually be used to design more complete investigations.

Stalcup et al. (1971) reported results obtained from four current meters moored in the Grenada Passage, and Burns and Carr (1975) analyzed 36 current meter

TABLE 1. CURRENT METER ARRAY DESCRIPTION (1)

PASSAGE	LAT (N)	LONG (N)	WATER DEPTH (m)	CM DEPTH (m)	DATA START	DATA END	DURATION OF DATA (DAYS)	INERTIAL PERIOD (HOURS)
St. Vincent								
A	13°25.4'	61°03.1'	915	105	30 Jan 77	24 May 77	114	
				380		24 May 77	114	51.69 (1.935 x 10^{-2}cph)
				880		22 May 77	112	
B(2)	13°25'	61°03'	850	105(3)	26 May 77	11 July 77	46	
				380		9 Nov 77	167	51.7 (1.93 x 10^{-2}cph)
				820		7 Nov 77	165	
Grenada	11°43.5'	61°55.5'	750	60(4)		25 Sept 77	238	
				110(4)	30 Jan 77	27 Apr 77	87	59.05 (1.693 x 10^{-2}cph)
				320		6 Nov 77	280	
				600		6 Nov 77	280	

(1) The sampling rate was four samples/hour.

(2) Position of current meter arrays A and B were approximately the same. The direction of flow at the near bottom current meter of array B, however, was inconsistent with that of array A. The deepest current meter of array B was 50 m shallower and the bottom depth 75 m shallower than at A. Apparently the positions differed, although both arrays were in the main channel. The time lapse between end of A and start at B was about 26 hours.

(3) The current meter at 105 m of array B ran for only 46 days and the raw data plot indicated that the operation was not continuous.

(4) Comparison of current meter temperature records and concurrent hydrographic profiles suggested that the 60 m and 110 m Grenada Passage instruments were about 70 m deeper than their nominal depths.

records obtained between Venezuela and Hispaniola. Twenty-two of these records were from various passages, while the rest were obtained elsewhere within the Caribbean. Smith (1974) reported data taken from twelve current meters, with one array of four current meters located near Jungfern Passage. A summary of the basic information from these three sources encompassed 29 measurements (Table 2). These records ranged between 14 and 47 days in length, with a mean of 26.7 days. The observation depths ranged between 45 and 1509 m. The reasons for selecting depths were seldom explained and are often difficult to rationalize. The mean velocities estimated from progressive vector diagrams were between 1 and 2 knots (kn) (1 kn = 51.4 cm/sec) in the upper layers, but they were generally moderate or low in the layer between the salinity maximum and minimum cores. Two current meters were located near the salinity maximum (at 100 m in Jungfern and at 85 m in Mona Passages), but both measured rather weak flow. Mean velocities at three current meters below the salinity minimum were less than 8 cm/sec. A majority of current records indicated one or more significant, or even sharp, changes in the direction of flow. No apparent periodicity appears in this variation of direction. Some records indicated considerable persistence in direction, while others changed direction randomly over intervals of 2 to 37 days.

These records were also variable at tidal frequencies. Energy spectra of the historical current meter data in Grenada Passage showed the semidiurnal tides at all measured depths. In St. Vincent and St. Lucia Passages, semidiurnal tides dominated in the upper layers, while near the bottom semidiurnal mixed tides were present that had a significant diurnal component. Most other current records showed that mixed semidiurnal tides had a considerable diurnal component of energy, except for the Guadalupe/Antigua and Jungfern Passages where the tide is predominantly diurnal and has a considerable semidiurnal component.

Additionally the presence of an overtide at about a six-hour period was reported for almost all current meter data except that from Grenada and Anegada Passages. Significant energy density was shown in at least half of the records at about an eight-hour period. In Mona Passage a 50-hour period was noticeable. Pronounced current fluctuations at the inertial period were present in Guadalupe/Antigua, Montserrat/Antigua and Mona Passages. Low frequency 360° turns of the current were observed in several cases at various depths, with periods between 3 and 12 days.

III. LOW FREQUENCY CURRENT FLUCTUATIONS IN THE GULF OF MEXICO AND THE STRAITS OF FLORIDA

Fluctuations of a four- to five-day period were reported in Yucatan Strait by Hansen and Molinari (1979) from one-month-long current meter data taken at 1977 m (15 m above the bottom). Wunsch and Wimbush (1977) showed large nontidal current variability in Florida Strait at 5 and 14 day periods. They related this variability to corresponding oscillations in wind forcing. Düing et al. (1977) used two years' data of current and temperature measurements in the Florida current off Miami to show that low frequency energy maxima occurred at periods of 2 to 4, 4 t 5, and 8 to 25 days. Fluctuations, especially in the 10-13 day period band, were coherent with these maxima, and the wind stress curl led current by three days. Kielman and Düing (1974), analyzing a 50-day current meter record off Miami, showed persistent current fluctuations at periods of about 5-6 days; the downstream component was six times larger than the cross-stream component and led by about one-quarter period. They found that mesoscale wind forcing might have been important for current fluctuations, but that local and large-scale wind effects were not significant. Niiler (1976) showed fluctuations at about 10-20 day periods

TABLE 2. CURRENT METER OBSERVATIONS IN THE ANTILLES PASSAGES (1)

PASSAGE	LOCATION LAT. LONG.	MONTH, YEAR	OBSERV. LENGTH DAYS	OBSERV. DEPTH (m)	WATER DEPTH (m)	MEAN VELOCITY CM/SEC (2)	MEAN (3) DIRECTION	TIDE (4)
Grenada	11°36'N;61°53'W	Mar-Apr 70	37	423	623	24	W	[illegible]
	"	"	"	623	"	19	NW	[illegible]
	11°31'N;61°53'W	Mar-Apr 70	"	225	477	10	NE 24; W 13	S
	"	"	"	427		21	NE 26; W 11	S
	11°08'N;61°35'W	Aug 72	15	130	140	10	NE	S
	11°51'N;61°46'W	May 72	24	45	640	47	SW	S
St. Vincent	13°30'N;61°08'W	June 72	22	45	1600	90	NW	S
	"	"	"	245	"	14	NW 20; NE 2	[illegible]
	"	"	"	1590	"	3	SE 1; NW 21	SM
	13°38'N;61°00'W	July 72	23	45	600	61	NW	S
	"	"	"	590	"	9	NW	SM
St. Lucia	14°19'N;60°55'W	July 72	14	45	1030	49	NW	S
	"	"	"	245	"	28	SSW	S
	"	"	22	1010	"	7	W 8; SW 14	SM
Dominica	15°02'N;61°16'W	July 72	22	290	2060	11	SW 14; S 8	SM
Guadelupe-Antigua	16°36'N;61°47'W	June 72	22	460	1045	5	SW	SM
Monserat-Antigua	16°54'N;62°03'W	June 72	18	260	760	6	N 8; WNW 10	SM
	"	"	22	745	"	5	WNW	SM
St. Martin St. Christopher	17°45'N;63°04'W	June-July 72	22	245	735	6	NW 3; SW 8; NNW 8; SW 3	SM
Anegada	18°32'N;64°02'W	June-July 72	22	280	2075	11	NE 17; NW 5	SM
Jungfern (5)	17°38'N;65°12'W	Apr-May 74	47	100	1564	10	SE	DM
	"	"	"	450	"	8	NW 21; SE 26	DM
	"	"	"	800	"	4	N 10; NE 37	DM
	"	"	14	1534	"	6	NE	DM
Mona	18°11'N;67°41'W	Sept-Oct 72	29	285	485	10	NE	SM
	18°19'N;68°00'W	Jan 72	28	85	575	15	SW 10; SE 18	SM
			"	560		4	W 17; NW 11	SM
	18°31'N;67°48'W	Oct 72	28	350	625	11	W 20; NNW 8	SM
	"	"	"	615	"	4	NE	SM

NOTES:

(1) The first four current meters (Geodyne #850) listed in the Table were by WHOI; sampling rate 15 minutes. The rest of the current meters (Geodyne A101) were by NAVOCEANO; sampling rate 10 minutes.

(2) Estimated mean velocity from progressive vector diagrams using 24 h mean data for WHOI and 12 h mean data for NAVOCEANO.

(3) General direction of progressive vector diagrams. When flow was in more than one direction, the adjacent figure indicates the duration of each episode.

(4) S = Semidiurnal.

SM = Semidiurnal mixed.

DM = Diurnal mixed.

(5) About 33 km to the west of the deepest part of Jungfern Channel. The deepest current meter was below the [illegible] level.

in the longshore currents on the western Florida Shelf and reported spectral properties similar to those of currents on the eastern Florida Shelf. Lee and Mayer (1977) found significant coherence between north-south currents at the shelf break (30 m isobath) off southwestern Florida and the east-west wind at a nine-day period, with the wind leading by about 90°. In the Florida current, meandering and fluctuations at periods of 5-7 days are persistent, as shown by Niiler (1975) in his extensive review of data, theory, and numerical models.

Similar forcing and interaction processes may operate in the eastern part of the Caribbean, which has not been as extensively studied as the Gulf of Mexico and the Straits of Florida. Meandering of trade winds at four- to five-day periods has been shown in the Caribbean area by Riehl (1954). Mofjeld and Wimbush (1977) showed high coherence between bottom pressure and local wind oscillations at a five-day period with a 4.5 hour phase lag in the eastern Caribbean.

Effects of local wind forcing on flow variability in the relatively narrow and shallow Lesser Antilles Passages may not be significant, but large-scale wind field fluctuations on both sides of the islands may be important. Other factors may also be considered in the passages and in the eastern Caribbean. It has been shown recently by Mazeika et al. (1980) and by Mazeika (1973) that intense mesoscale eddies, which may affect low frequency flow variability farther west, occur east of the Lesser Antilles. Thus, the temporal variability and occurrence of subinertial energy peaks in various frequency bands at different locations in the eastern Caribbean may result from a complex interaction of fluctuations in intensity and direction of wind forcing at various frequencies. Internal factors may also play a role.

IV. PRESENTATION OF RESULTS

Current meter data presented in this study are of much longer duration than any of the previous observations summarized in Table 1. The depths for current meters were selected to measure flow in the layer of strong baroclinicity which is near and above the salinity maximum, to measure flow in a thick intermediate layer between the salinity maximum and minimum cores, and to measure flow in the near-bottom layer. Vertical distributions of temperature and salinity, the location of current meters, and the mean flow for the day of hydrographic measurements in St. Vincent Passage are shown in Figures 2a and 2b. The temperature and salinity distributions are shown for Grenada Passage in Figure 3a and 3b one day after deployment of the current meter array and Figure 3c and 3d for three weeks later. Considerable change in the temperature and salinity distributions is noticeable between the two sections.

Most of the records contained few suspicious data, but there were some exceptions. In St. Vincent Passage array B was placed close to the position of array A, and began operation 26 hours after array A was recovered (Table 1). The deep current meters on these two arrays, however, showed mean flows in opposite directions and much different amplitudes of east-west semidiurnal tides (Table 6). We have no other reason to suspect these records: the abrupt differences may have been caused by local topography (both instruments were within 30 m of bottom). The 105 m record of array B was short (46 days) and noisy, so we have excluded it from most discussions. The Grenada records at 110 m and 320 m were noisier than the remainder of the records, but appear quite usable for our purposes. Additionally, an array was deployed in St. Lucia Passage, but was not recovered.

Tables 3 and 4 show the percent frequency distributions of speed and temperature, and their means. A high percentage of speeds (Table 3) in the range of 30-40 cm/sec occurred at all depths, but only the shallowest current meters showed high percentages in the range of 70-80 cm/sec. Percent frequency of temperature (Table 4) shows a decreasing range of temperature with depth, as usual. Discrepancies occurred in the temperature records for the Grenada Passage at 60 m and 110 m between current meter and CTD data. Temperature differences indicate about 70 m greater depth than nominal for the two current meters.

Seasonal frequency distributions of speeds are shown in Figure 4 for St. Vincent Passage and in Figure 5 for Grenada Passage. There are changes in the frequency distribution between winter and summer that may indicate some trends, but no conclusions on seasonal variability can be made at this point.

The most conspicuous events in direction of flow are summarized in Table 5 and can be compared with the progressive vector diagrams presented in Figures 6 through 8. Typical examples of change in direction, circular rotation, and stagnation (speed <3 cm/sec) are shown in Figure 9 by segments of progressive vector diagrams with points of two-hour averaged speed and direction. Stagnation at 105 m (array A, St. Vincent Passage) on March 17-25 (Table 5) actually occurred as a slow cyclonic circling (about 5 circles) visible on a large-scale, two-hour average progressive vector diagram (not shown). Also the stagnation that occurred during July 2-9 at 600 m in Grenada Passage was actually several slow anticyclonic rotations. Significant low frequency changes in current direction occurred with these data even more often than with the previously described historical data. Persistence in the same direction ranged between 3 and 130 days. Frequencies of long-period rotations with these data are similar to the historical data described above, ranging from 3 to 18 days. Direction changes were frequently uncorrelated between various depths at the same array and appeared as random events. Such changes may suggest current reversals throughout the passage, but may also be meanders or translations of narrow currents. Obviously a single current meter array in a passage is not sufficient to detect the cause for direction change and the mechanism by which flow is reorganized. Extensive synoptic data may be required on both sides of the islands and in the passages to understand the nature of the forcing, the process of this change, and the effects on the hydrographic distribution.

Table 6 lists resultant (vector mean) speed, direction, and persistence for each record. Persistence is defined as the ratio of resultant speed to scalar mean speed, expressed in percent, and is a measure of the directionality of the flow. For example, a unidirectional flow would have a persistence of 100%. Scalar mean speeds ranged from 23.5 cm/sec to 51.5 cm/sec, with most in the range of 20 to 30 cm/sec. Resultant speeds varied from 8.5 cm/sec to 45.8 cm/sec, with most in the range from 14 cm/sec to 22 cm/sec. The persistences were high, varying from 36% to 91%. Only one record had a persistence below 49%. In addition, Table 6 shows major tidal flow constituents. A least-square fit of a periodic trial function, using the Gauss-Seidel technique, was applied to the u and v current components. The maximum number of points that can be handled by the program is 16,280 (170 days). The purpose was to obtain a first look at tidal signatures; therefore, no block averaging of data was attempted.

Daily vectors are shown in Figures 10 through 12. In the two near-bottom St. Vincent records a clear oscillation appears which has a peak-to-peak amplitude of about 20 to 30 cm/sec and a period of about 10 to 15 days. At the Grenada mooring, the 60 m and 600 m records had longer period fluctuations. These

TABLE 3. PERCENT FREQUENCY DISTRIBUTION OF CURRENT SPEED

PASSAGE	DEPTH (m)	SPEED CM/SEC 0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–>80	MEAN SPEED CM/SEC
St. Vincent											
A	105	1.4	5.8	9.7	15.1	15.6	15.2	16.1	12.7	8.4	51.5
	380	16.6	31.6	21.5	17.0	9.4	3.3	0.5	0.1		23.3
	880	6.5	16.0	14.7	17.3	19.4	14.6	8.0	3.1	0.4	37.2
B	380	12.5	27.7	19.5	16.6	12.3	8.4	2.6	0.4		27.6
	820	13.0	30.8	27.9	17.7	7.4	2.5	0.6	0.1		23.6
Grenada	60	6.4	18.4	20.8	19.3	13.6	9.6	7.4	2.7	1.8	34.8
	110	26.3	22.1	16.6	11.3	7.1	4.5	3.8	2.6	5.5	28.1
	320	15.0	25.6	23.6	17.2	10.3	6.3	1.7	0.3		25.8
	600	17.5	25.2	26.0	20.2	8.4	2.4	0.3			23.5

TABLE 4. PERCENT FREQUENCY DISTRIBUTION OF TEMPERATURE FROM CURRENT METERS

PASSAGE	DEPTH (m)	°C													
		4	6	8	10	12	14	16	18	20	22	24	26	28	MEAN
St. Vincent															
A	105						0.16	2.53	13.18	23.86	42.41	17.56	0.30		22.19
	380			2.86	60.22	36.46	0.46								11.70
	880	87.33	12.67												5.52
B	380			0.92	43.93	53.58	1.57								12.10
	820	74.76	25.24												5.61
Grenada	60 (1)				0.01	0.53	4.06	36.65	45.31	13.29	0.15				18.34
	110 (1)				0.42	12.04	60.67	21.79	5.08						15.39
	320			1.46	55.94	42.46	0.14								11.82
	620		95.76	4.24											7.11

(1) Temperature at 60 m was about 4° and at 110 m ~3° lower than CTD temperatures at the hydrographic stations on both sides of the current meter array. The current meters were apparently about 70 m deeper than indicated.

TABLE 5. MAJOR DIRECTION VARIATIONS OF FLOW

PASSAGE	CURRENT METER DEPTH (m)	DIRECTION OF FLOW (1)	STAGNATION (2) (DATES)	ROTATION DATES	ROTATION DURATION (DAYS)	ROTATION CHARACTERISTICS
St. Vincent						
A	105	WNW 17; NW 38; NNW 25; W 5; NW 2	March 17-25			
	380	NNW 14; NW 32	March 6-11	March 17-May 26	40	Cyclonic; 4 full rotations in sequence
	880	NNW 35; NW 48; E 5; NW 5		March 1-9	8	Anticyclonic; full circle
B	380	NW 116; S 5; W 5	Sept 25-Oct 2 Nov 2-5			
	820	NE	June 13-16 Sept 24-30	Oct 24-28	4	Anticyclonic; semicircle
Grenada	60	W 24; WSW 130; SW 16; WSW 40		July 7-16 Aug 1-9	9 8	Anticyclonic; full circle Cyclonic; semicircle
	110	N 20; NE 58		Feb 27-March 11 April 18-May 2	12 8	Cyclonic; semicircle Cyclonic; semicircle
	320	E 4; WNW 13; SW 10; NW 35;NNW42 NW 17; NNW 47	Feb 16-19 Feb 22-26 March 1-7 July 13-14 Aug 10-18 Oct 11-14	March 13-17 April 18-May 2 July 7-25	4 14 18	Cyclonic; semicircle Anticyclonic; full circle Anticyclonic; full circle
	600	WSW	July 2-9	April 22-25 May 5-13	3 8	Cyclonic; full circle Cyclonic; full circle

(1) Mean general directions estimated from progressive vector diagrams. Significant changes in direction are shown in sequence with adjacent figures indicating number of days in the corresponding direction.

(2) Stagnation is defined as an extended period (2 or more days) when the current speeds are very [illegible].

TABLE 6. MEAN RESULTANT FLOW AND TIDAL COMPONENTS (1)

PASSAGE	DEPTH (m)	E-W (cm/sec)	N-S (cm/sec)	RESULTANT SPEED (cm/sec)	DIRECTION (True) (°)	PERSISTENCE (%)	E-W Tidal Constituents Ampl. (cm/sec) M_2	S_2	N_2	K_1	O_1	NONTIDAL VAR. %	N-S Tidal Constituents Ampl. (cm/sec) M_2	S_2	N_2	K_1	O_1	NONTIDAL VAR. %
[illegible] Current																		
[illegible]	[illegible]	-30.9[illegible]	33.44	45.82	[illegible]	83	16.28	4.69	3.01	[illegible]	[illegible]	[illegible]	8.41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	38	-7.18	4.56	8.52	303	36	20.10	7.60	5.42	1.49	[illegible]	41	11.74	3.87	[illegible]	[illegible]	[illegible]	[illegible]
	38	-9.3[illegible]	15.74	15.63	328	50	19.82	6.11	4.57	0.58	1.4[illegible]	[illegible]	8.89	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	-18.[illegible]	8.65	[illegible]0.03	296	73	20.18	7.76	4.74	1.57	[illegible]	4	[illegible]	3.9[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	14.91	064	63	1.04	1.73	0.94	0.44	[illegible]	99	7.66	3.16	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	21.33	[illegible]	90	9.03	3.06	1.58	[illegible]	.78	91	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	16.[illegible]	16.5[illegible]	01[illegible]	60	1.85	1.20	0.77	[illegible]	[illegible]	98	7.44	[illegible]	1.3[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	1.[illegible]	333	49	2.51	0.43	0.84	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	21.49	[illegible]	91	9.55	3.41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

(1) [illegible] values [illegible] the north and east.

fluctuations were less regular and had fewer realizations than the shorter period oscillations in St. Vincent Passage. The peak-to-peak amplitude was about 60 cm/sec at 60 m depth and about 40 cm/sec at 600 m depth. The period of these fluctuations appeared to be from 50 to 90 days. Similar fluctuations may have existed in the St. Vincent records, but the length (167 days or less) was too short to define clearly fluctuations that were 50 to 90 days long.

Spectra were computed on all unfiltered records (except for array B, 105 m) using the BMDX92 package developed by the UCLA Health Science Computing Facility. For all records the mean and linear trends were removed before computing the spectra. A few large and isolated spikes were removed from the temperature records, and beginning and ending transients were removed from the temperature and velocity records; but the records were not otherwise manipulated. Figures 13-21 show the spectra of velocity (east-west and north-south components) and temperature, and Table 7 lists the variance distributions from these calculations. In all velocity records a considerable variance existed at the lowest frequency estimates (up to 77% of the variance, see Table 7), a prominent semidiurnal tidal peak (11% to 67% of the variance), and the energetic peaks at tidal harmonic frequencies (up to 35% of the variance), especially in St. Vincent Passage. Temperature spectra showed similar characteristics: considerable low frequency variance (up to 86%), prominent semidurnal peaks (4% to 82%), and energetic tidal harmonics (up to 25%). With these rather wide-band estimates (0.0156 CPH), neither the diurnal tide nor inertial oscillations show as distinct peaks. Tidal frequencies were eliminated to investigate low frequency variability. Spectra were computed using the BMDX routines after low-pass filtering with a cutoff period of about 48 hours (Figs. 22, 23, and 24). Both near-bottom records from St. Vincent show peaks near a 12-13 day period (0.0033 CPH), corresponding to the oscillations seen in the daily vector diagrams (Figs. 10-12). Less pronounced peaks are shown in the records from shallower depths, corresponding to periods near 35 or 70 days (about 1.2×10^{-3} CPH or 6×10^{-4} CPH). The Grenada Passage records had a broad peak near 70 days (6×10^{-4}CPH) and a possible weak peak near 26 days (2×10^{-3} CPH). Figures 25 through 29 show coherences of u and v components between various depths at the three current meter arrays.

TABLE 7. VARIANCE DISTRIBUTION (1)

CURRENT METER	DAYS	FLOW (2) TOTAL VARIANCE $(CM/SEC)^2$	FLOW (2) % Low Frequency	FLOW (2) % Diurnal	FLOW (2) % Semidiurnal	FLOW (2) % Harmonics	TEMPERATURE (2) TOTAL VARIANCE $(^oC)^2$	TEMPERATURE (2) % Low Frequency	TEMPERATURE (2) % Diurnal	TEMPERATURE (2) % Semidiurnal	TEMPERATURE (2) % Harmonics
St. Vincent											
A 105 m	114	959	64.1	1.3	23.0	4.3	4.07	63.7	0.5	28.9	[illegible]
380 m	114	608	30.2	1.0	60.1	[illegible]	0.77	38.1	1.5	39.7	[illegible]
880 m	112	1356	22.9	0.6	40.3	[illegible]	0.19	13.6	0.5	[illegible]	[illegible]
B 380 m	167	499	19.2	1.5	67.2	[illegible]	0.64	35.7	[illegible]	36.6	[illegible]
820 m	165	482	14.7	0.9	32.5	35.1	0.29	8.2	0.4	82.1	[illegible]
Grenada											
60 m	238	600	77.0	1.7	12.9	2.0	1.68	62.0	1.7	[illegible]	[illegible]
110 m	87	1245	44.5	4.5	11.2	7.4	[illegible]	79.1	1.4	13.5	[illegible]
320 m	280	751	60.0	4.1	12.3	5.3	0.65	78.1	[illegible]	[illegible]	[illegible]
600 m	280	267	69.9	1.3	25.0	0.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

(1) As defined in unfiltered spectra.

(2) Low: Two lowest estimates.

Diurnal:	Estimate centered on	0.031 cph
Semidiurnal:	Two estimates	0.078, 0.094 cph
Harmonics:	sum of 1st	0.16 , 0.17 cph
	2nd	0.23 , 0.25 cph
	3rd	0.31 , 0.33 cph
	4th	0.39 , 0.40 cph
	5th	0.48 , 0.50 cph
Width of estimates:		0.0156 cph

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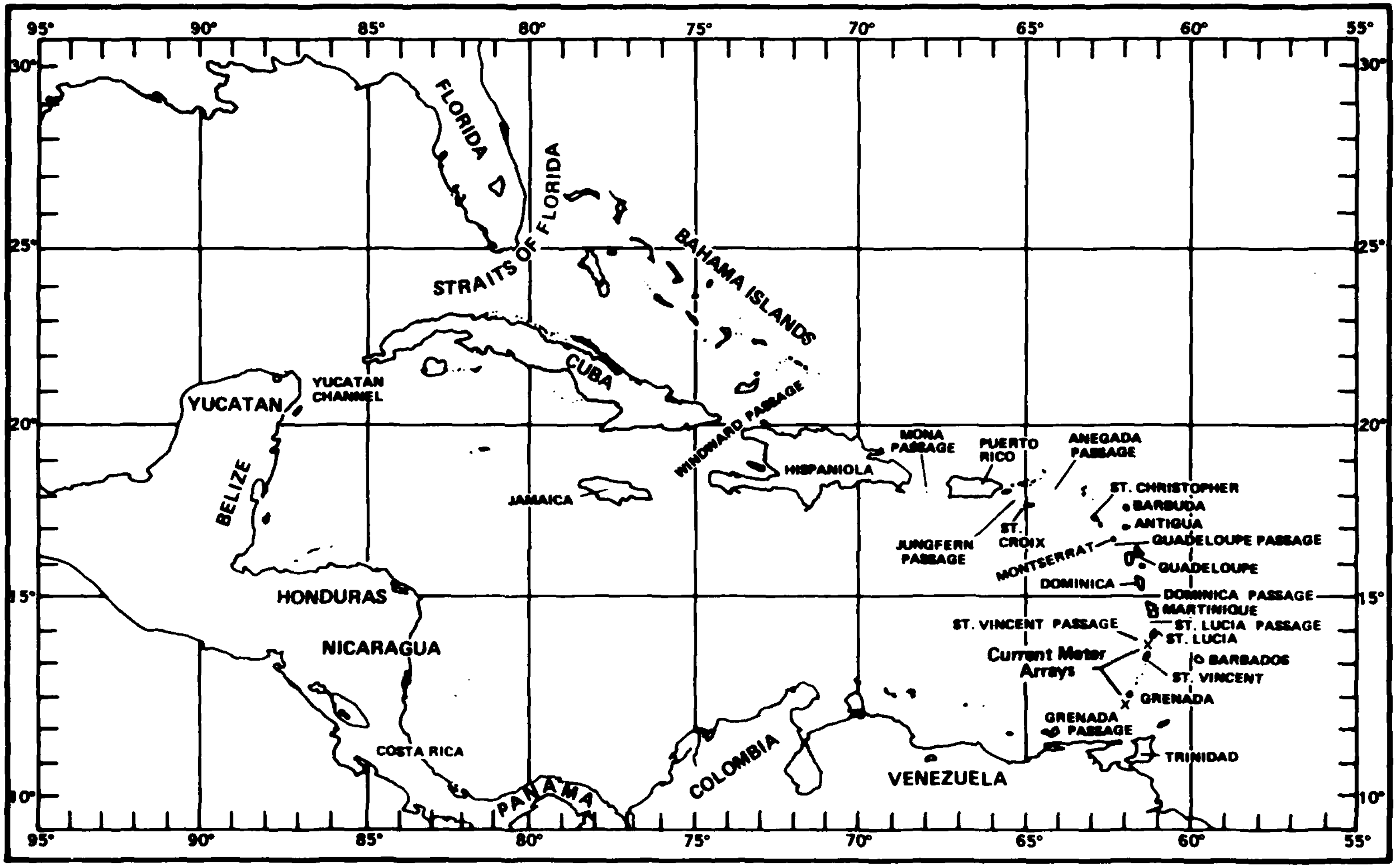

Figure 1. General view of the Caribbean area. Locations of current meter arrays are indicated by crosses.

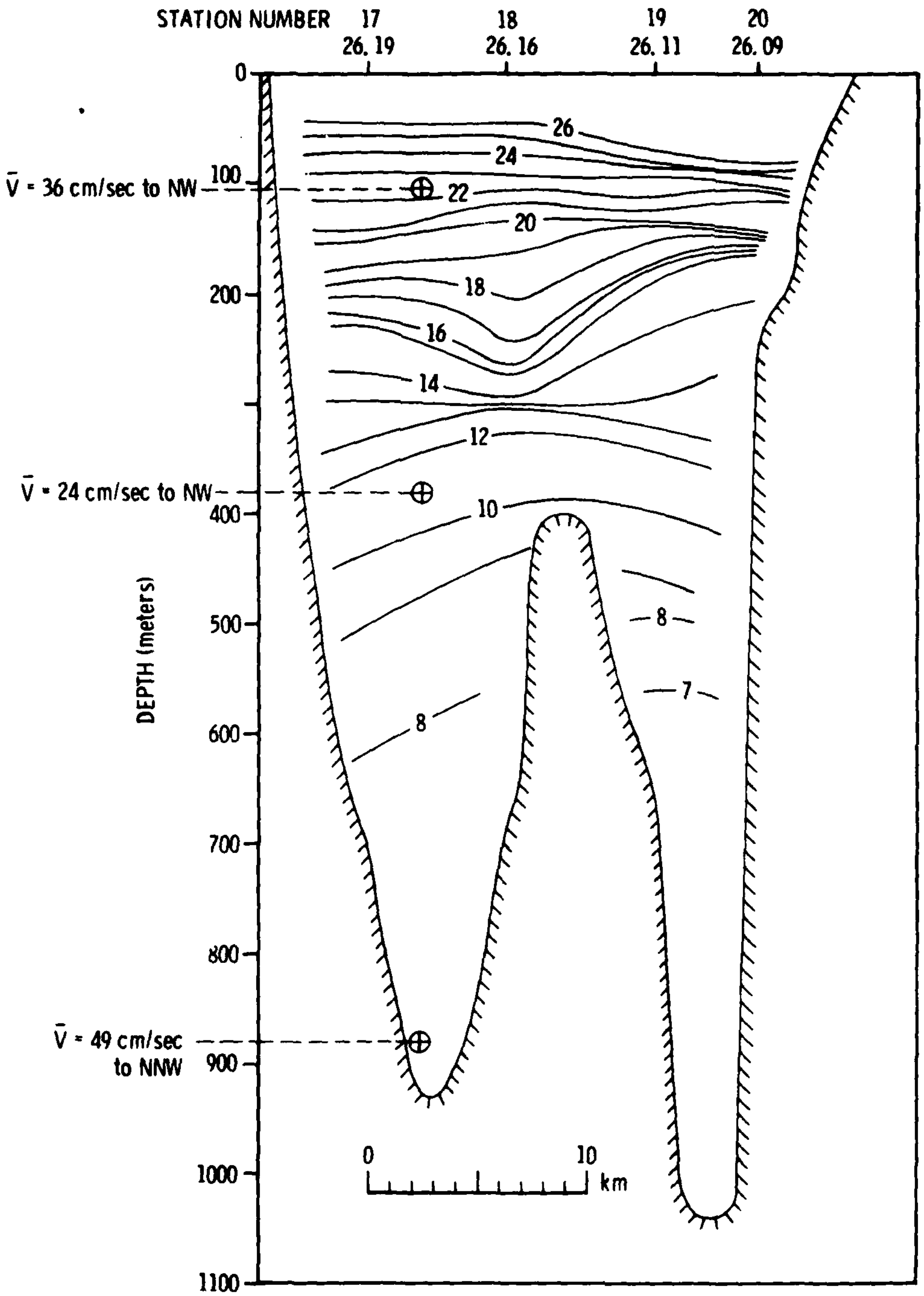

Figure 2a. Vertical temperature (°C) distribution in St. Vincent Passage. Circled crosses show current meter locations. The mean velocities and directions shown at each current meter were computed for the day of hydrographic data (3 February, 1977; 5 days after deployment of the current meter array). The main channel is on the left (south side). The trench on the right side is a canyon in the western end of the passage, while on the eastern end the bottom depth is less than 400 m.

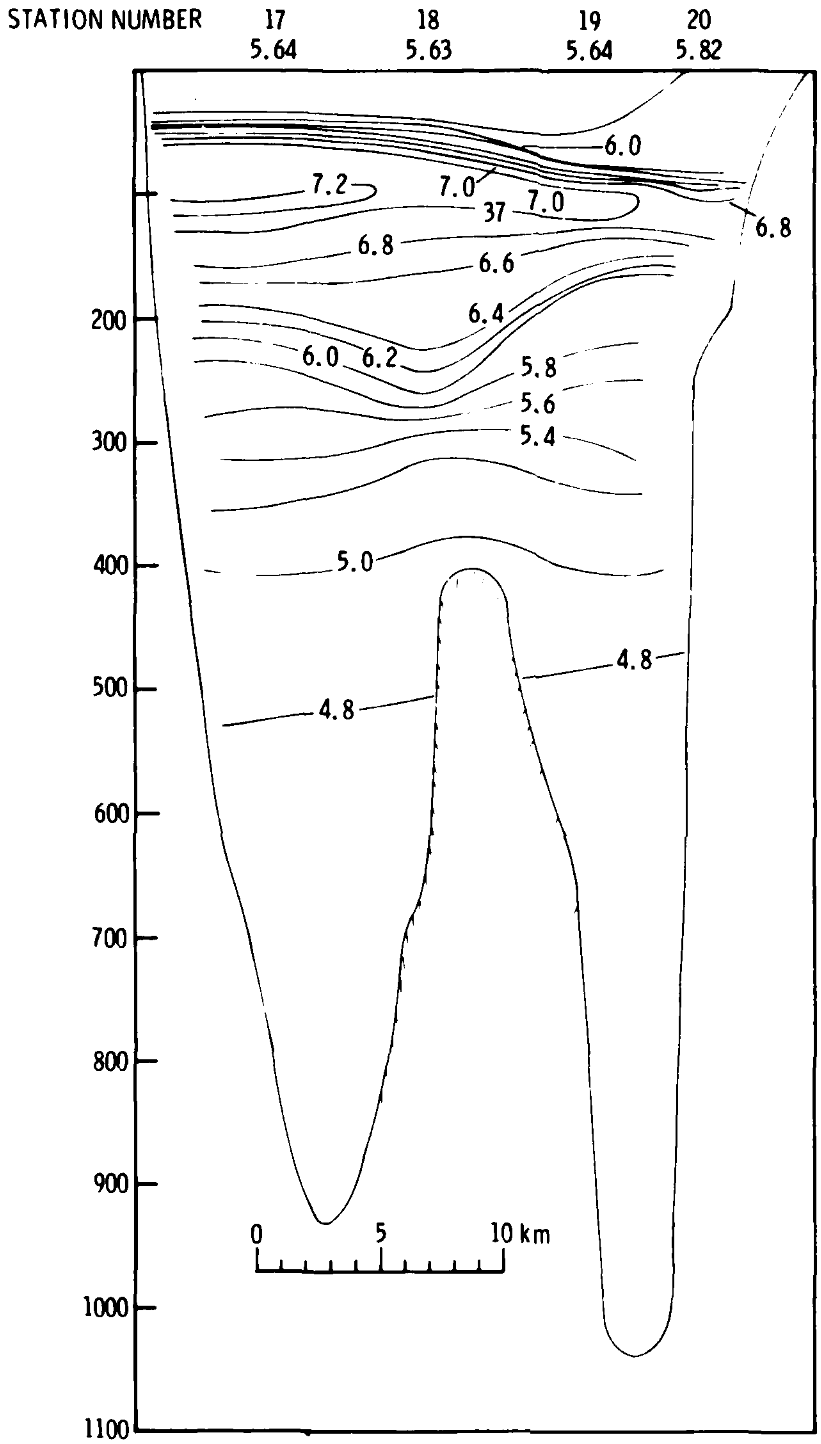

Figure 2b. Vertical salinity (‰) distribution (less 30 ‰) in St. Vincent passage, 3 February 1977.

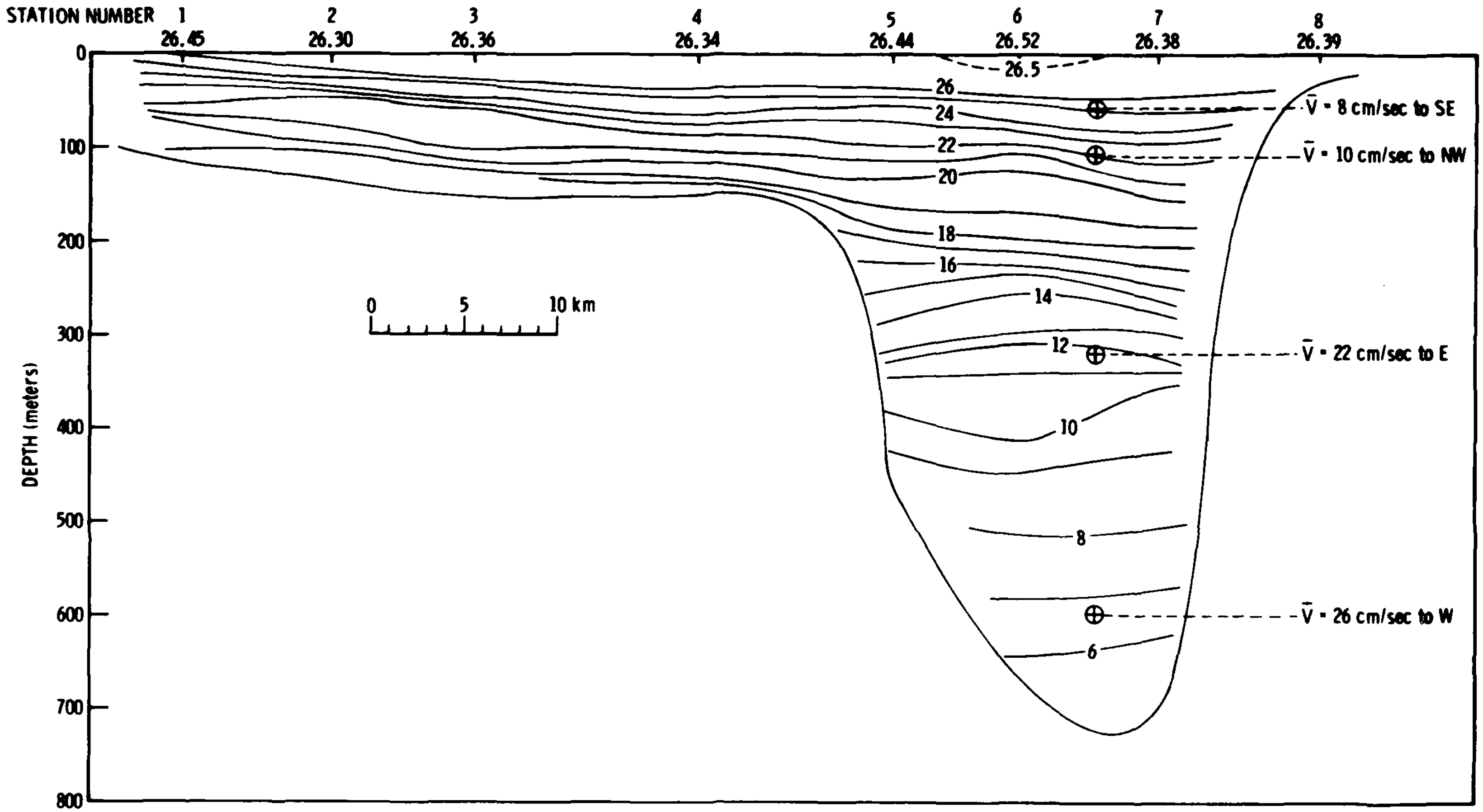

Figure 3a. Vertical temperature (°C) distribution in Grenada passage, 30 January 1977. Circled crosses show current meter locations. The mean velocities and directions shown at each current meter were computed for the day of hydrographic data (one day after deployment of current meter array).

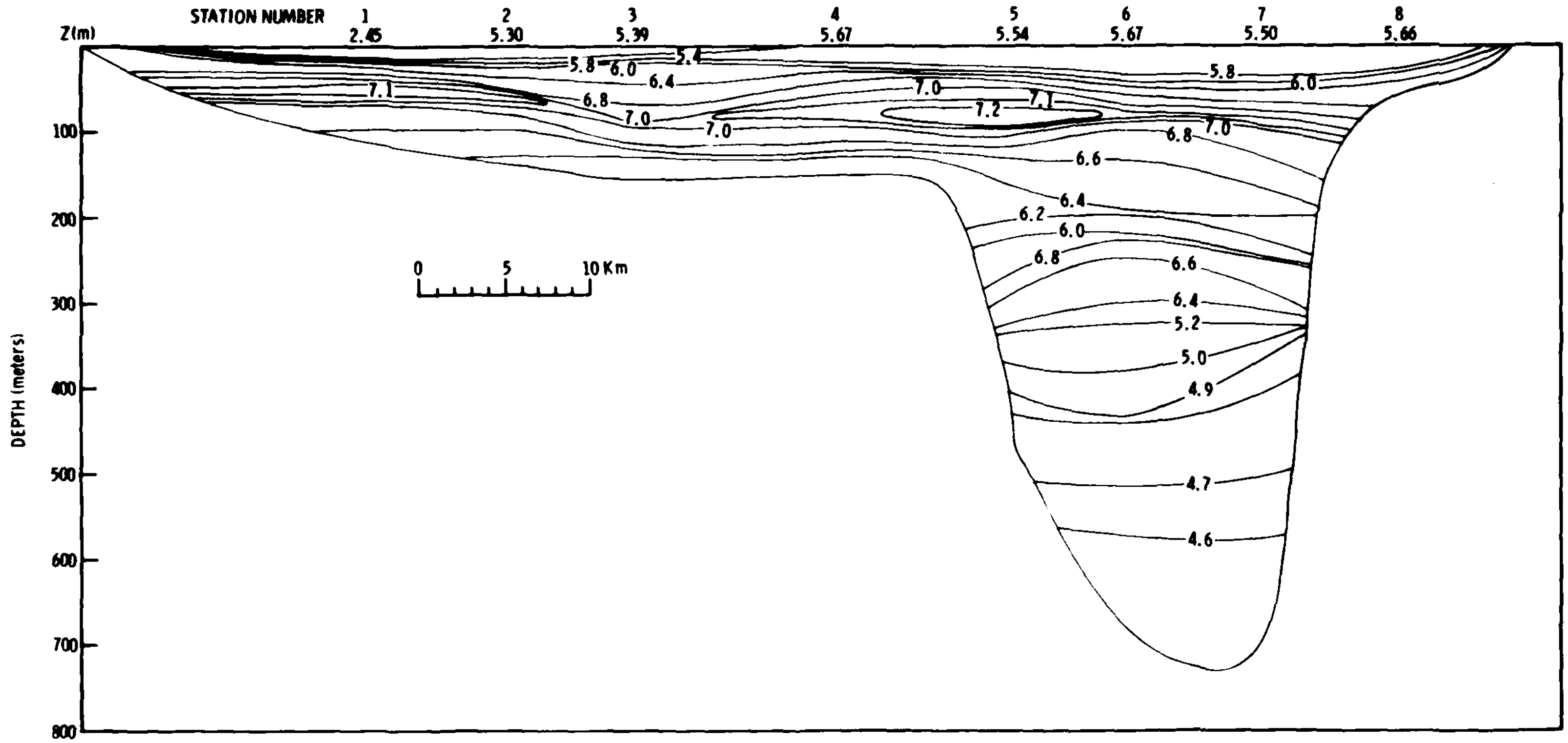

Figure 3b. Vertical salinity (‰) distribution (less 30‰) in Grenada Passage, 30 January 1977.

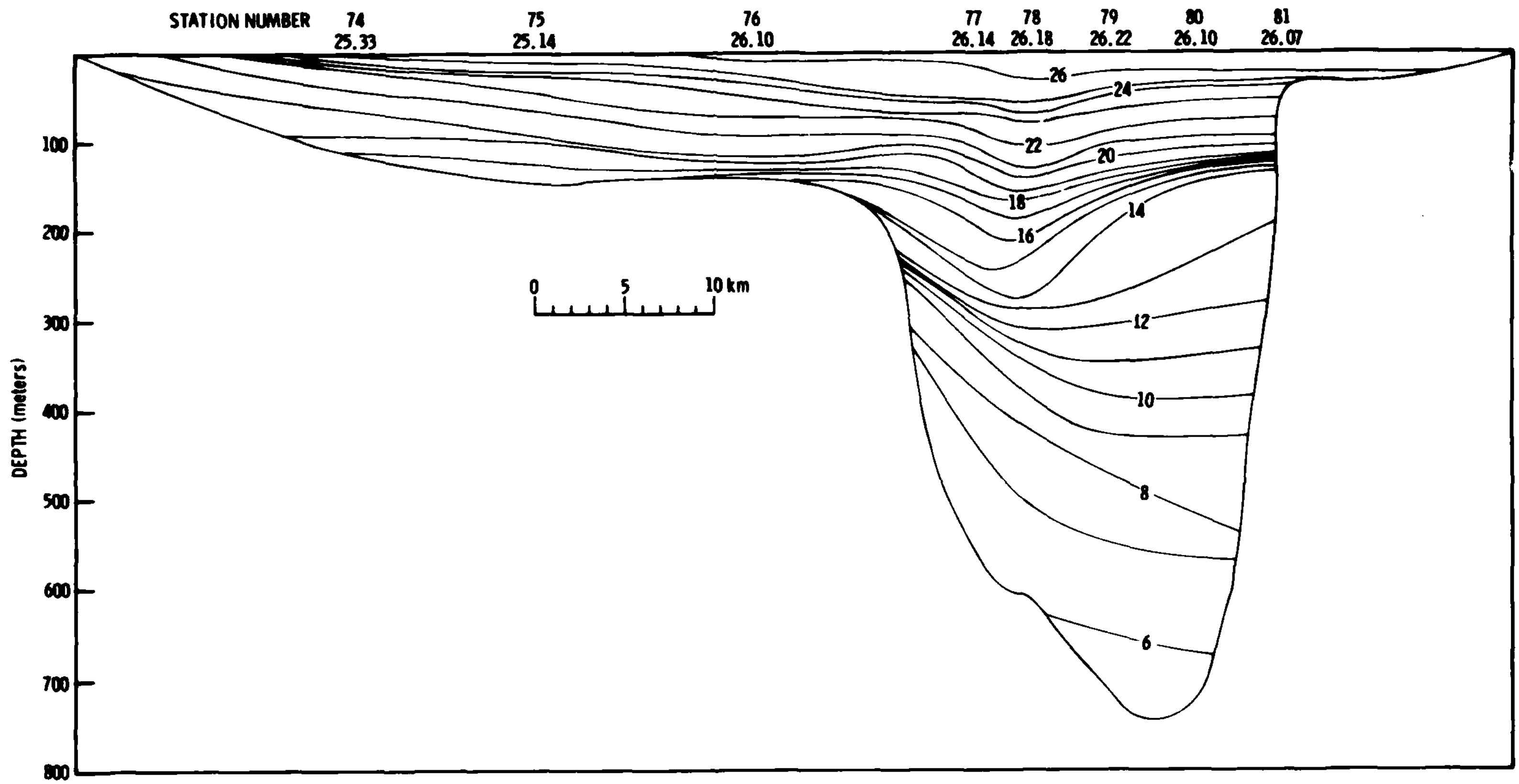

Figure 3c. Vertical temperature (°C) distribution in Grenada Passage, 18 February 1977.

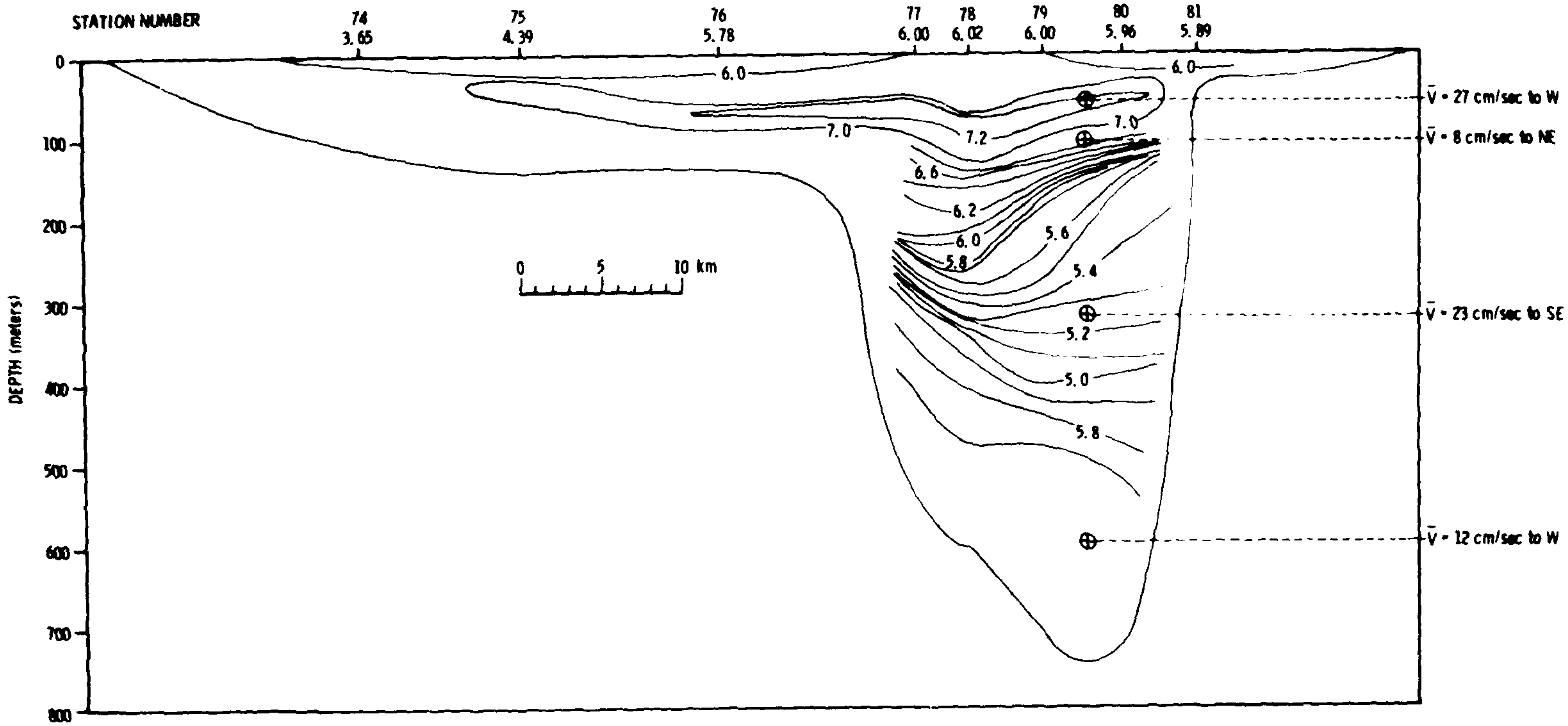

Figure 3d. Vertical salinity (‰) distribution (less 30‰) in Grenada Passage, 18 February 1977. Circled crosses show current meter locations. The mean velocities and directions shown at each current meter were computed for the day of hydrographic data (20 days after deployment of current meter array).

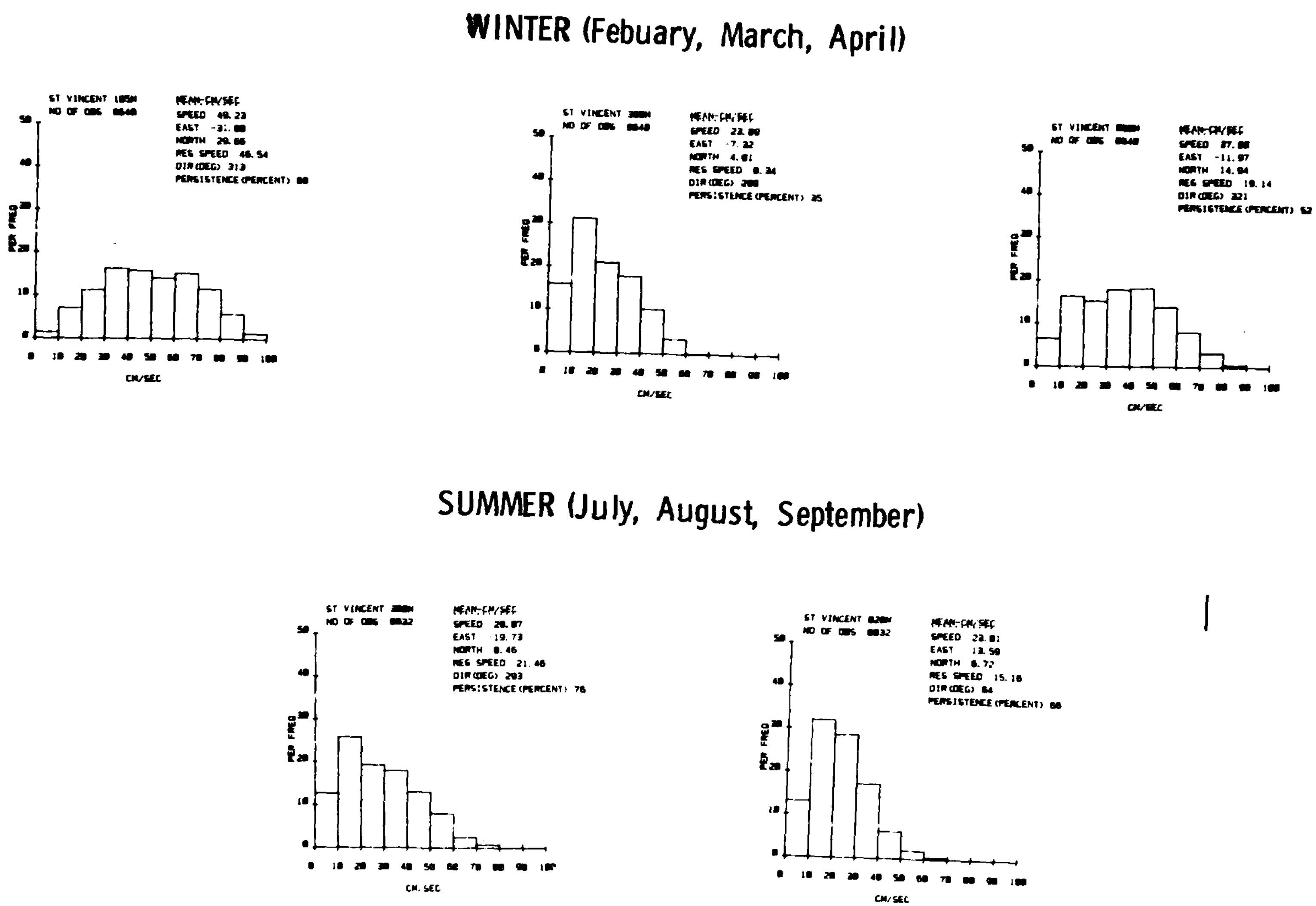

Figure 4. Seasonal (winter and summer) speed histogram in St. Vincent Passage.

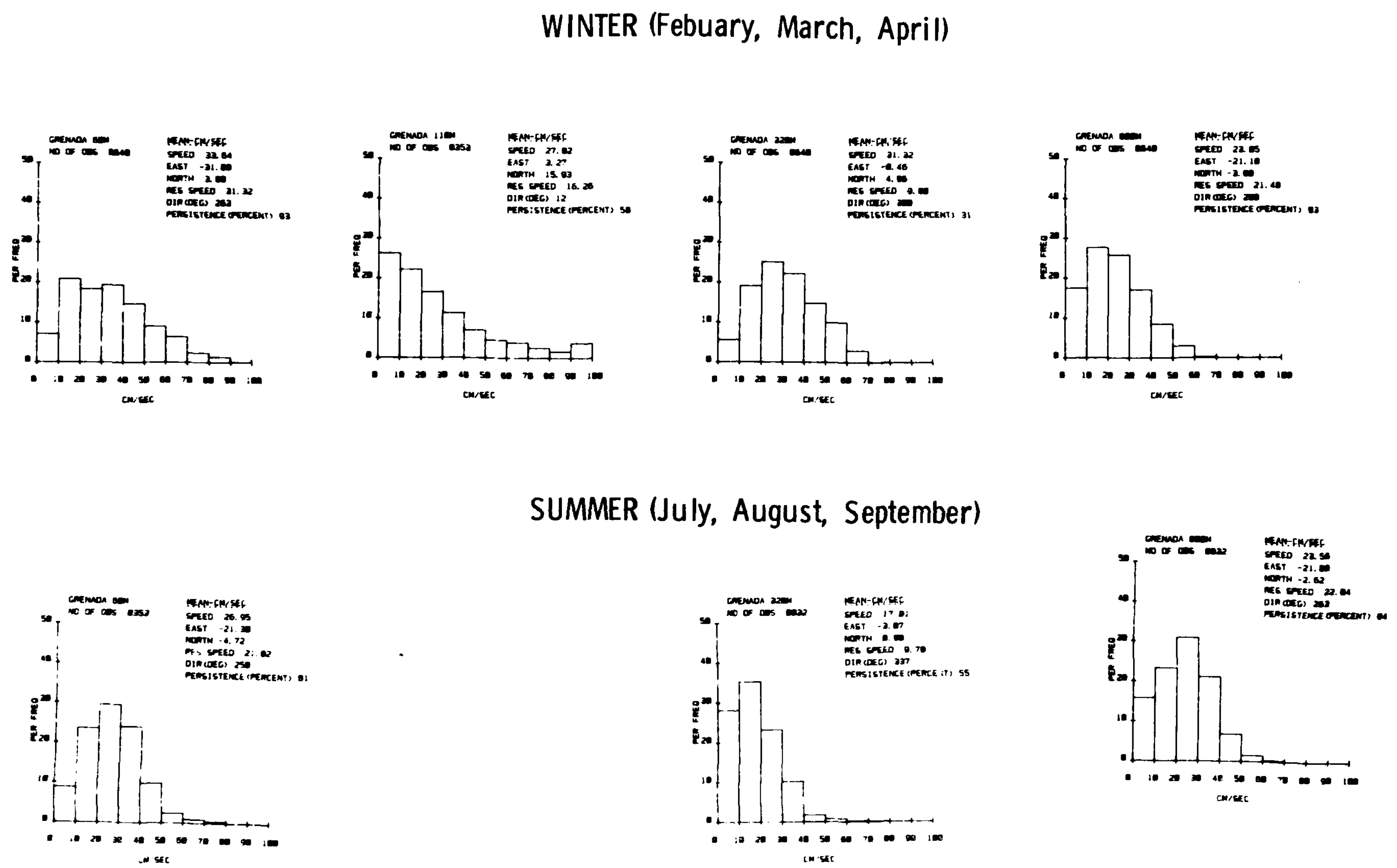

Figure 5. Seasonal (winter and summer) speed histogram in Grenada Passage.

ST. VINCENT PASSAGE A 105M

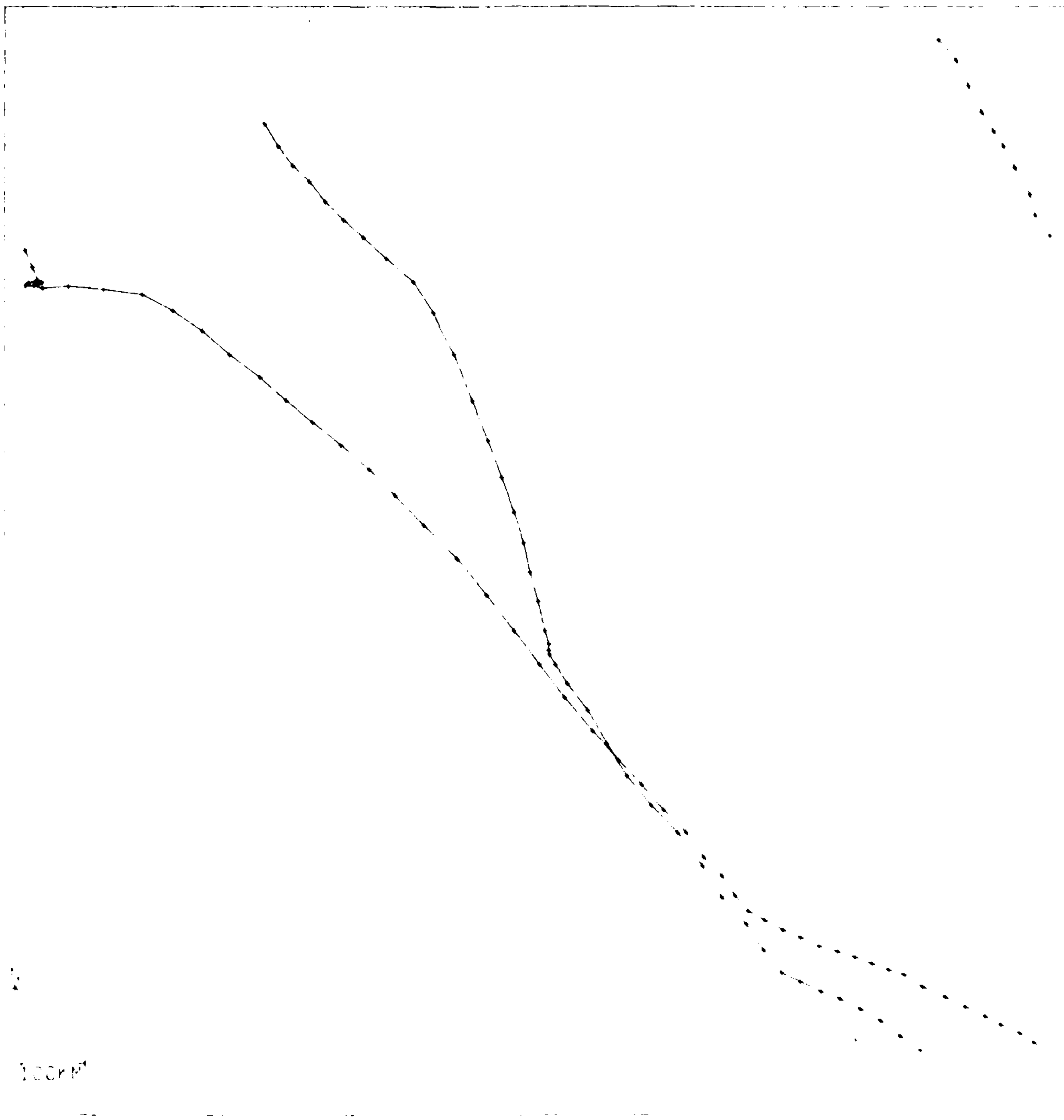

Figure 6a. Progressive vector diagram at 105 m in St. Vincent passage (current meter array A, see Table 1). Each point is a 24 hour resultant vector. S indicates the start of a diagram; adjacent is the first continuation. The second continuation is a short segment in the upper right corner. Both continuations are northwestward.

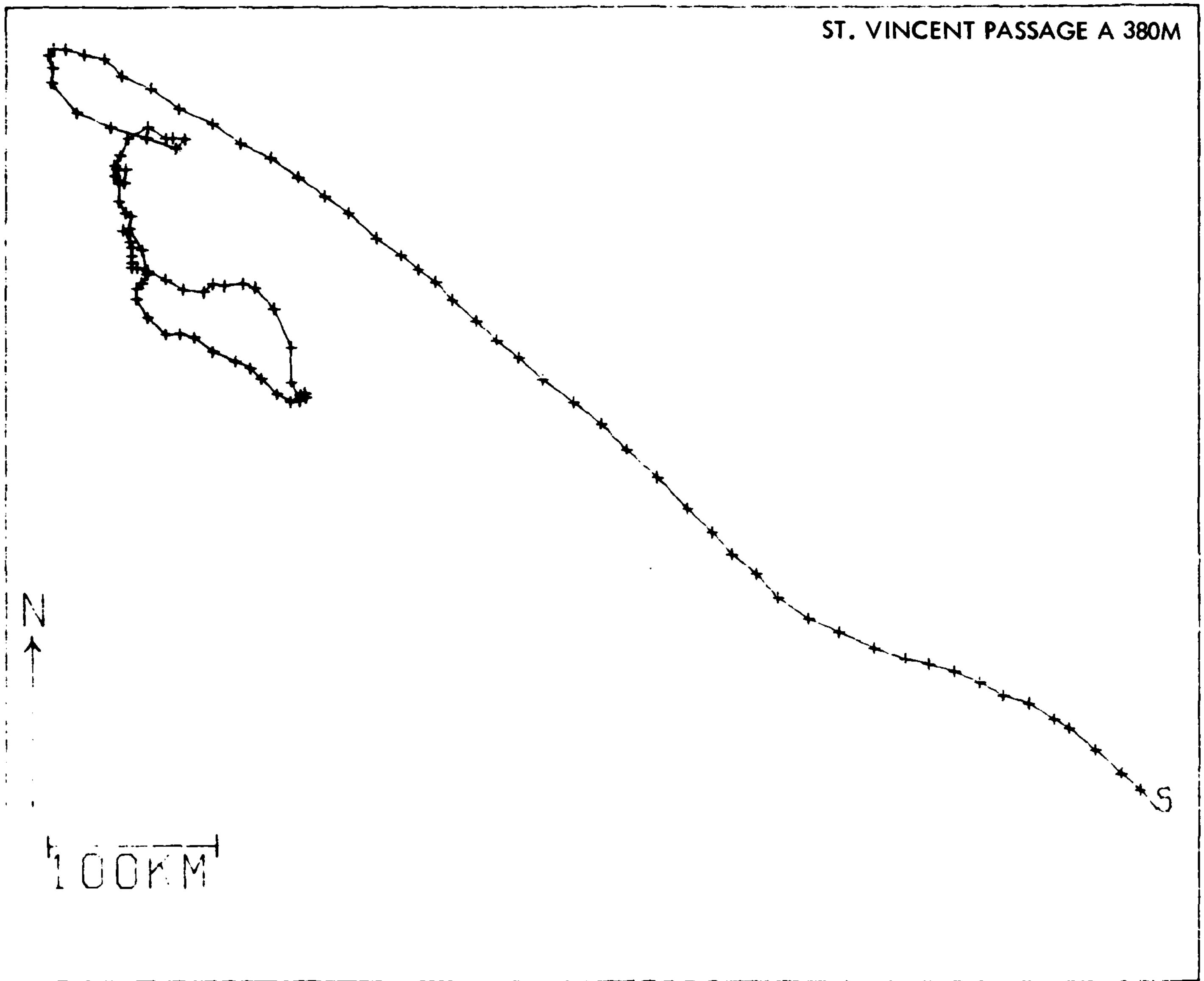

Figure 6b. Progressive vector diagram at 380 m in St. Vincent Passage (array A).

ST. VINCENT PASSAGE A 880M

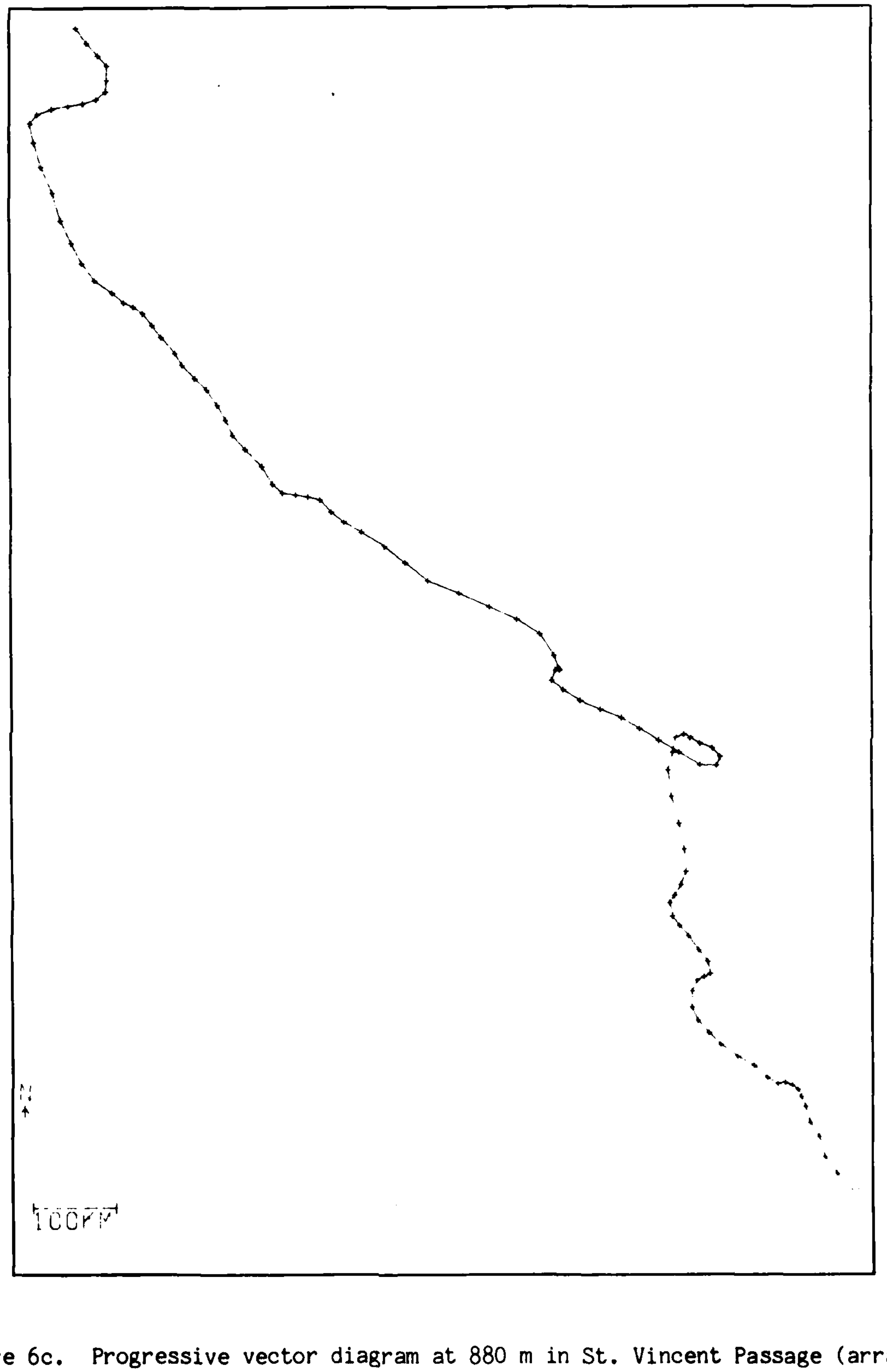

Figure 6c. Progressive vector diagram at 880 m in St. Vincent Passage (array A)

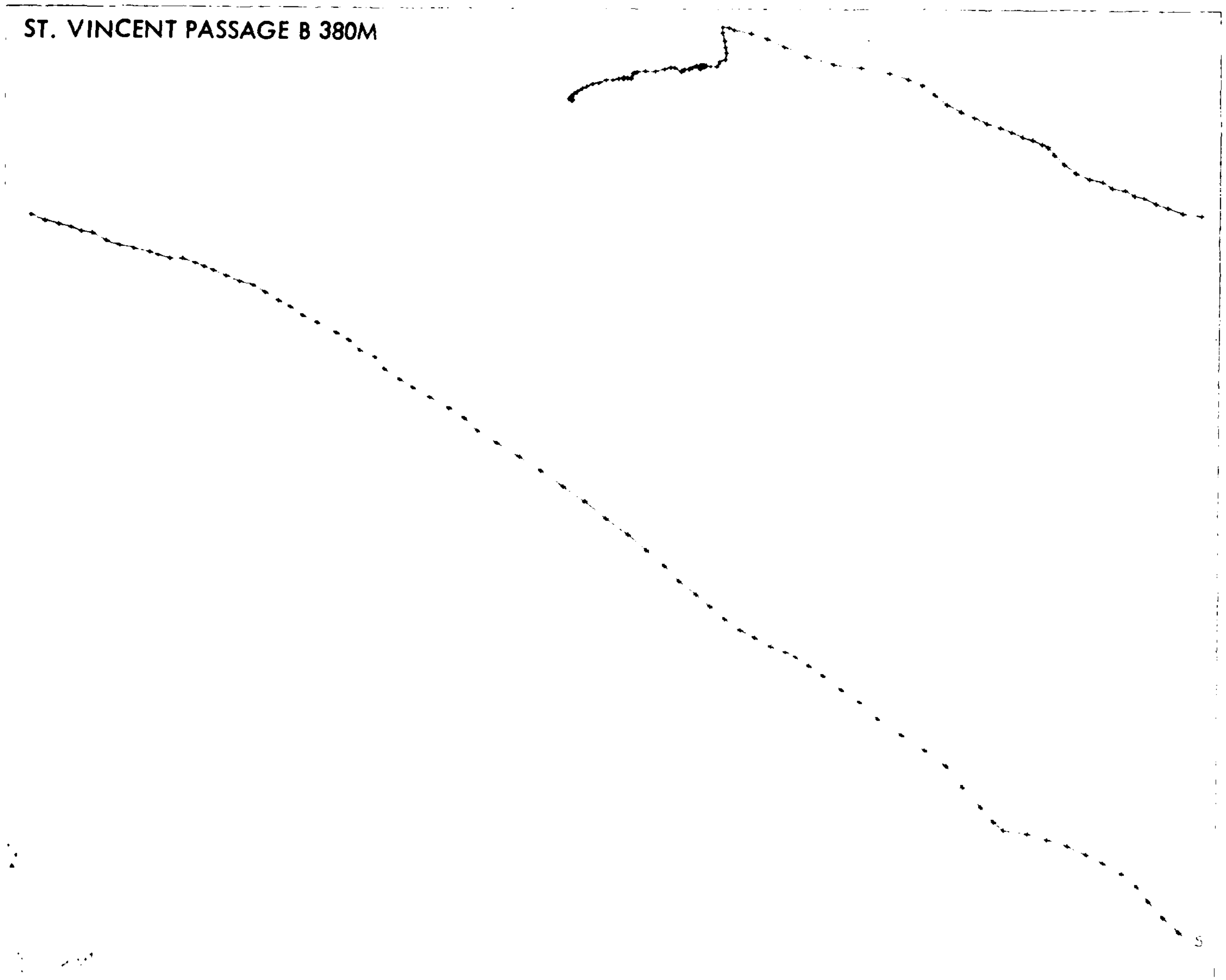

Figure 7a. Progressive vector diagram at 380 m in St. Vincent Passage (array B; see Table 1). The upper segment is a continuation westward.

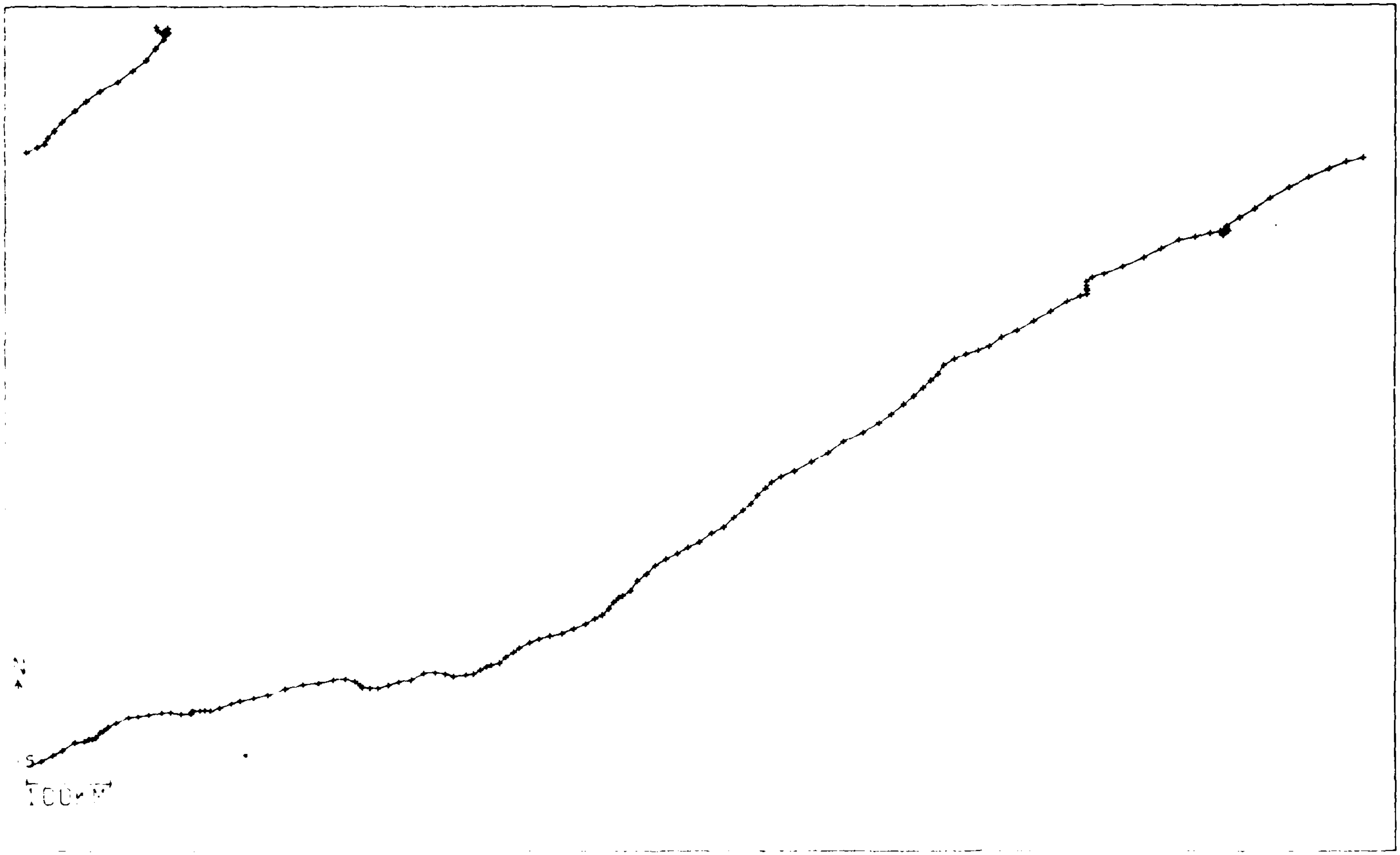

Figure 7b. Progressive vector diagram at 820 m in St. Vincent Passage (array B). The upper segment is a continuation northeastward.

GRENADA PASSAGE 60M

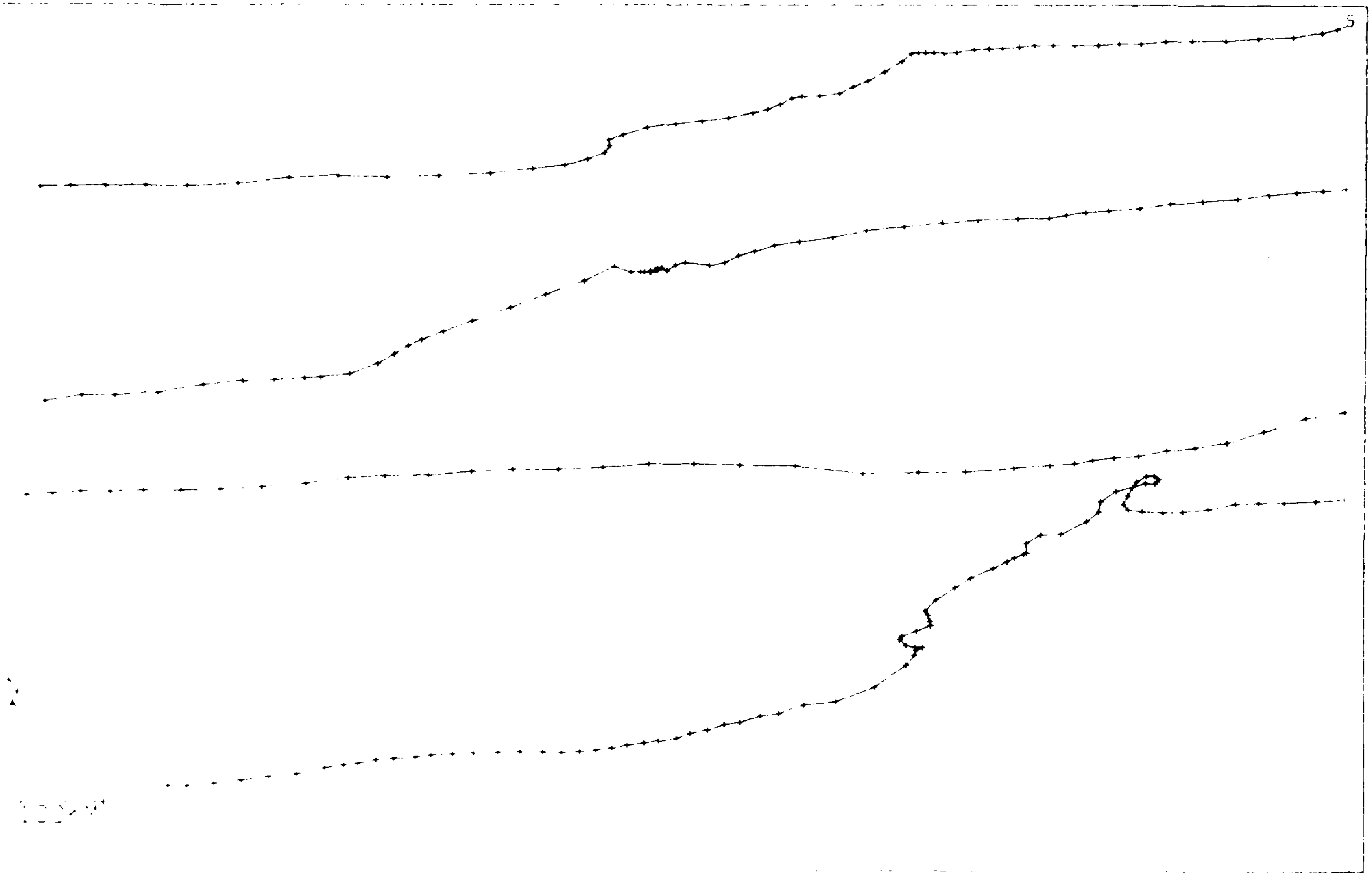

Figure 8a. Progressive vector diagram at 60 m in Grenada Passage (Table 1). Continuations are in sequence from the top to bottom, flowing westward.

GRENADA PASSAGE 110M

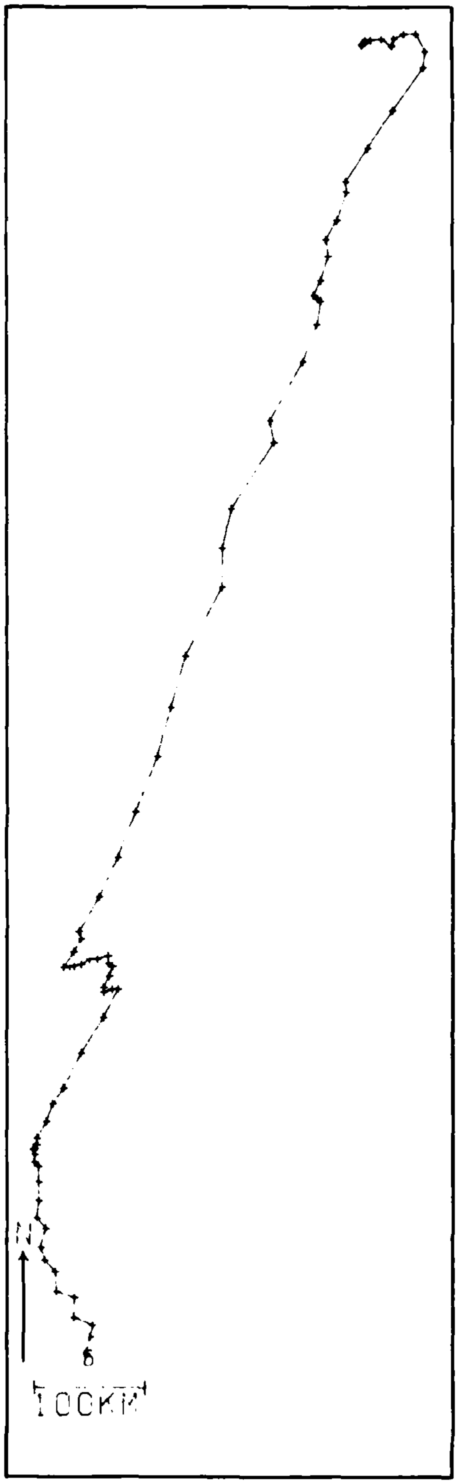

Figure 8b. Progressive vector diagram at 110 m in Grenada Passage.

GRENADA PASSAGE 320M

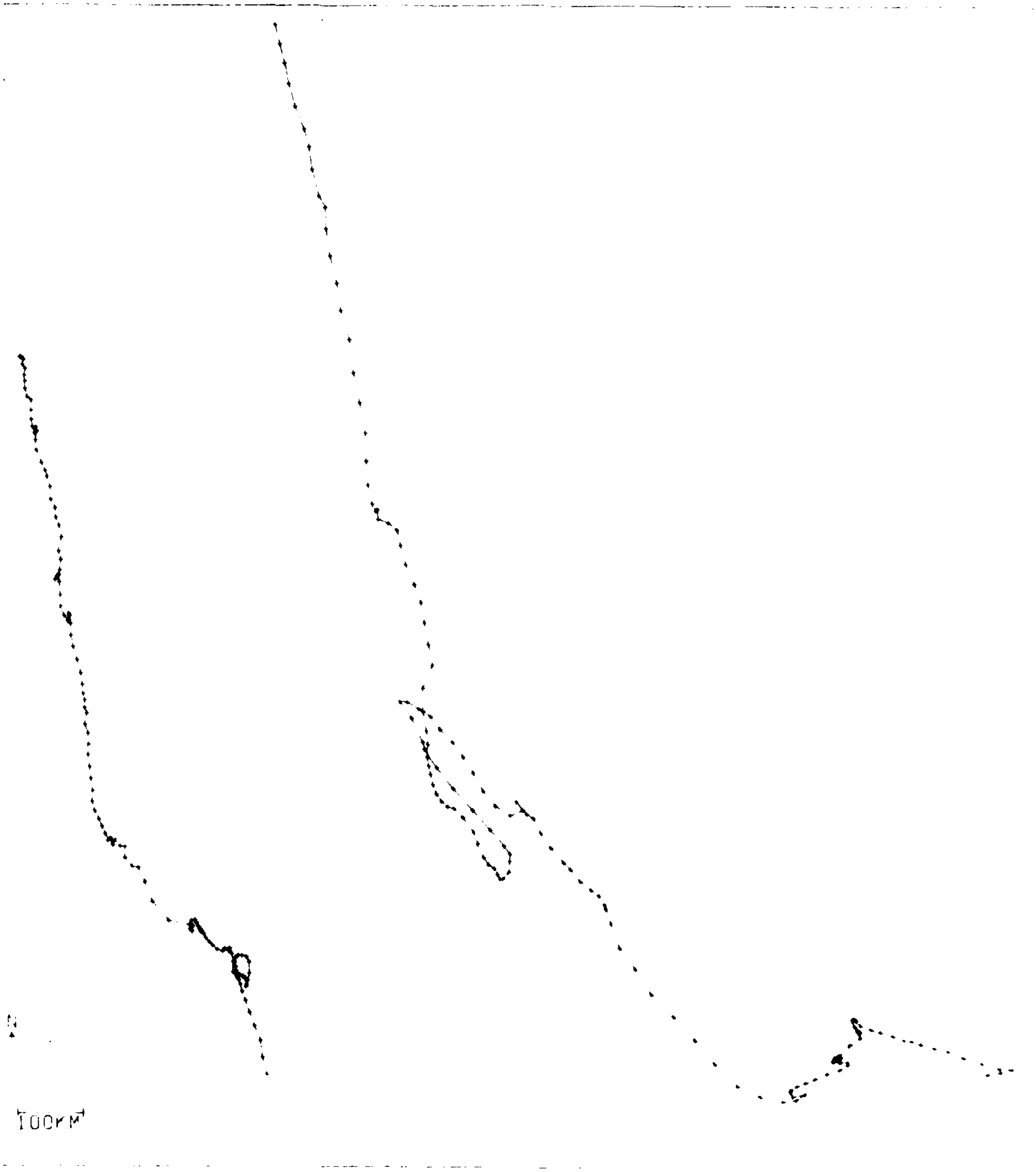

Figure 8c. Progressive vector diagram at 320 m in Grenada Passage. The continuations at the left side flow northward.

GRENADA PASSAGE 600M

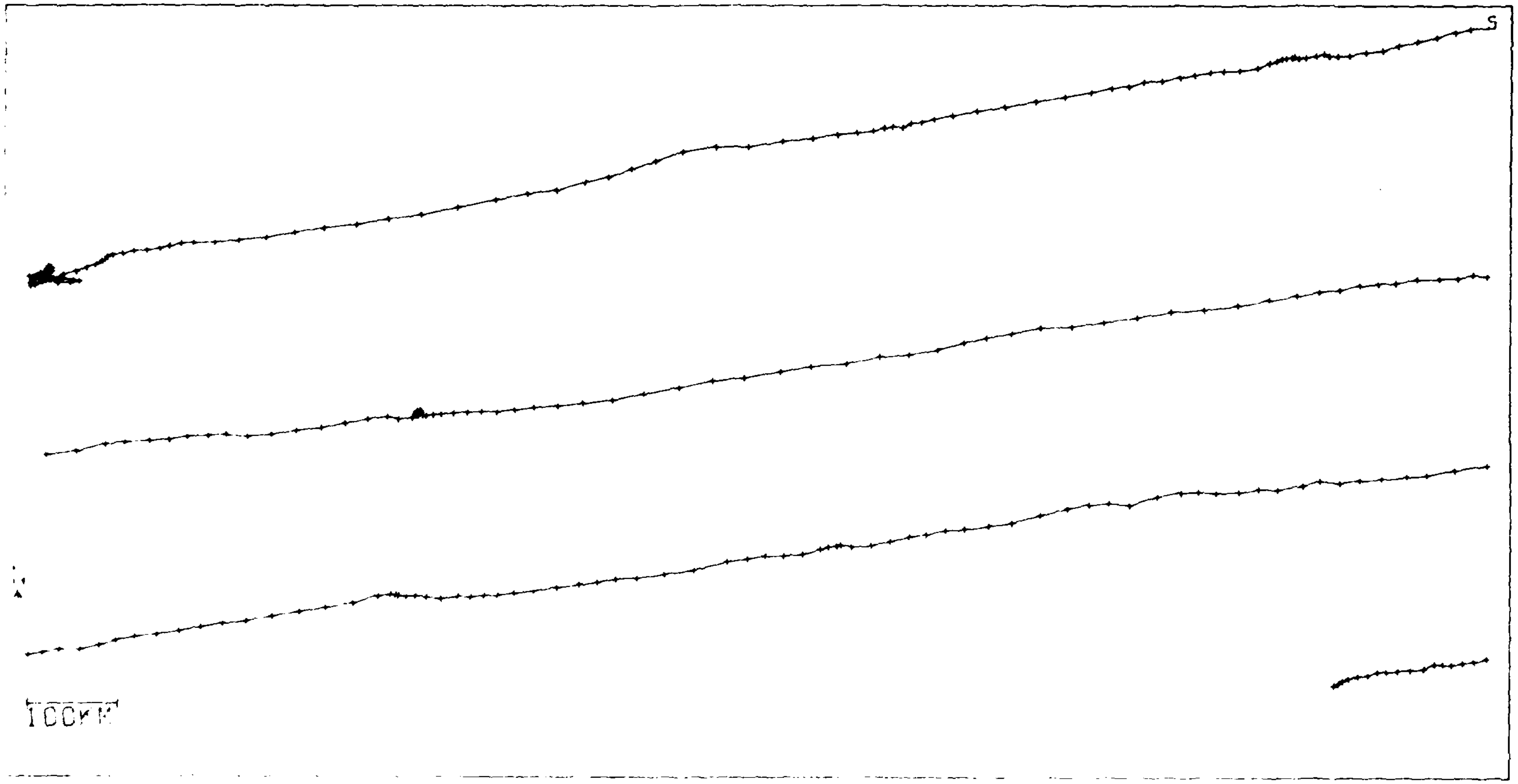

Figure 8d. Progressive vector diagram at 600 m in Grenada Passage. Continuations are in sequence from top to bottom, flowing westward.

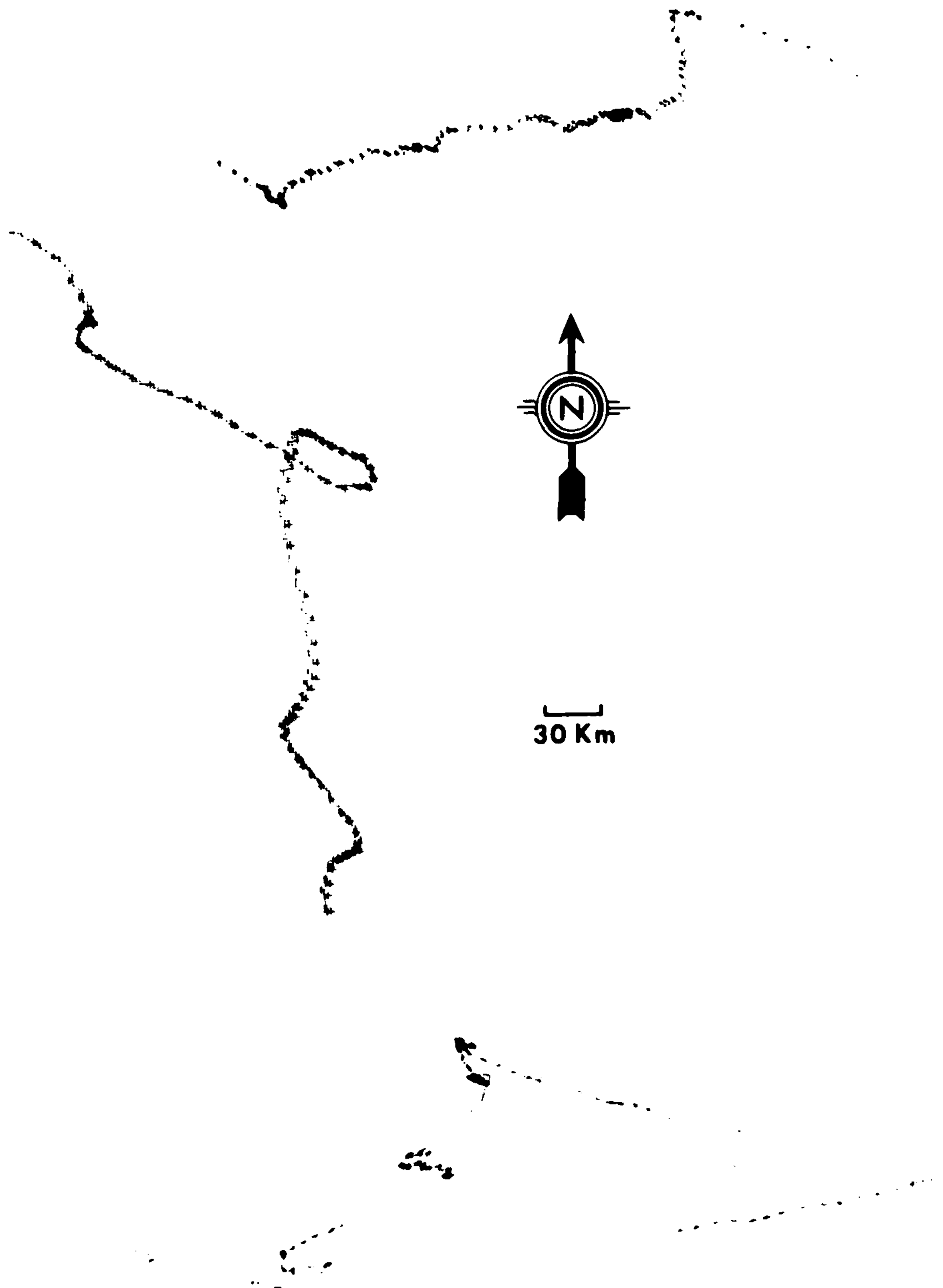

Figure 9. Segments of progressive vector diagrams illustrating changes in direction. Each point represents a 2 hour average.
upper: St. Vincent, 380, 28 Oct-3 Nov
middle: St. Vincent, 880 m, 16 Feb-28 March
lower: Grenada, 320 m, 30 Jan-21 March

ST. VINCENT PASSAGE A

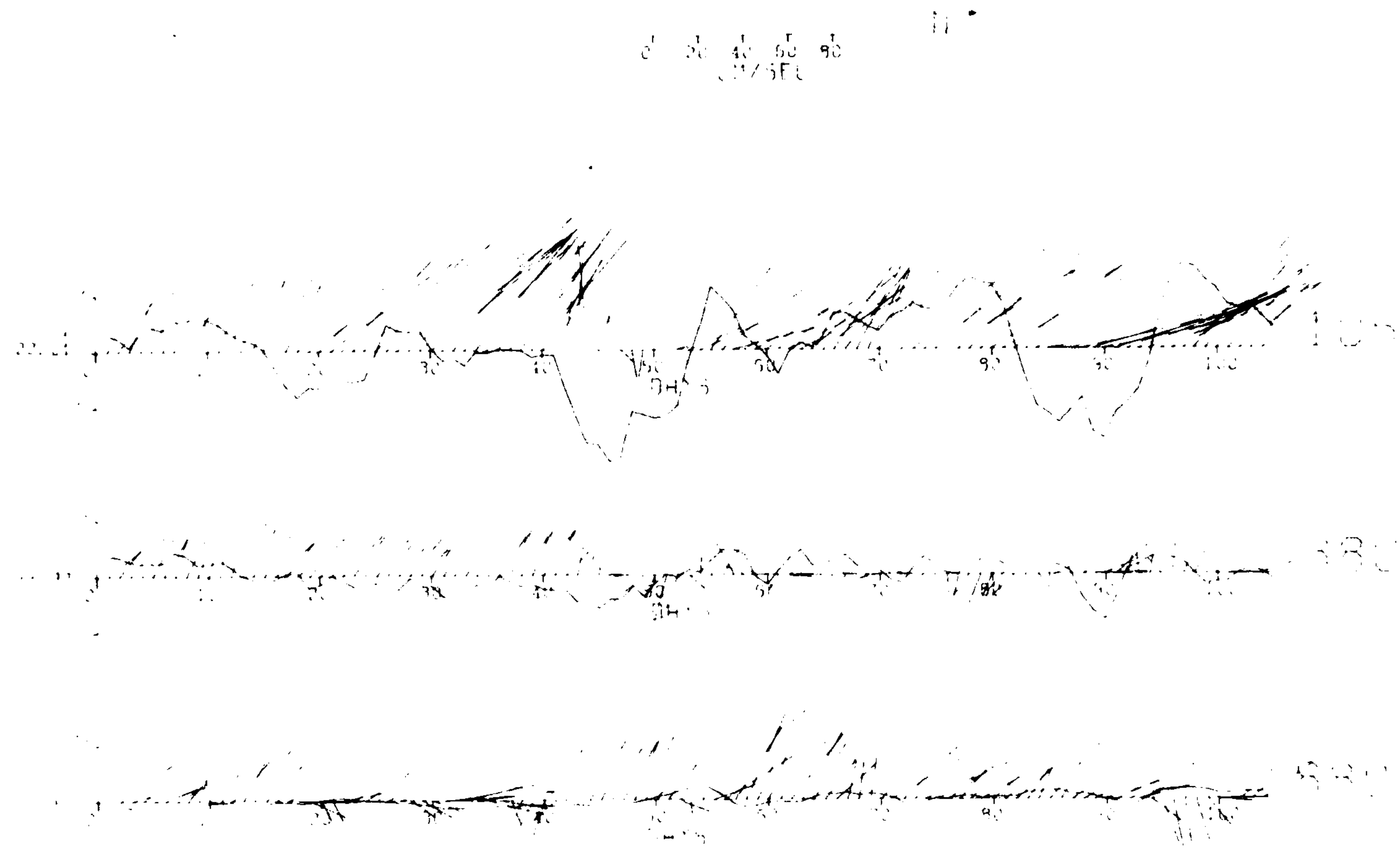

Figure 10. Daily vectors of flow and temperature (continuous line) from low-pass filtered data, St. Vincent Passage, array A (see Table 1). The number to the left of the temperature scale is the record mean.

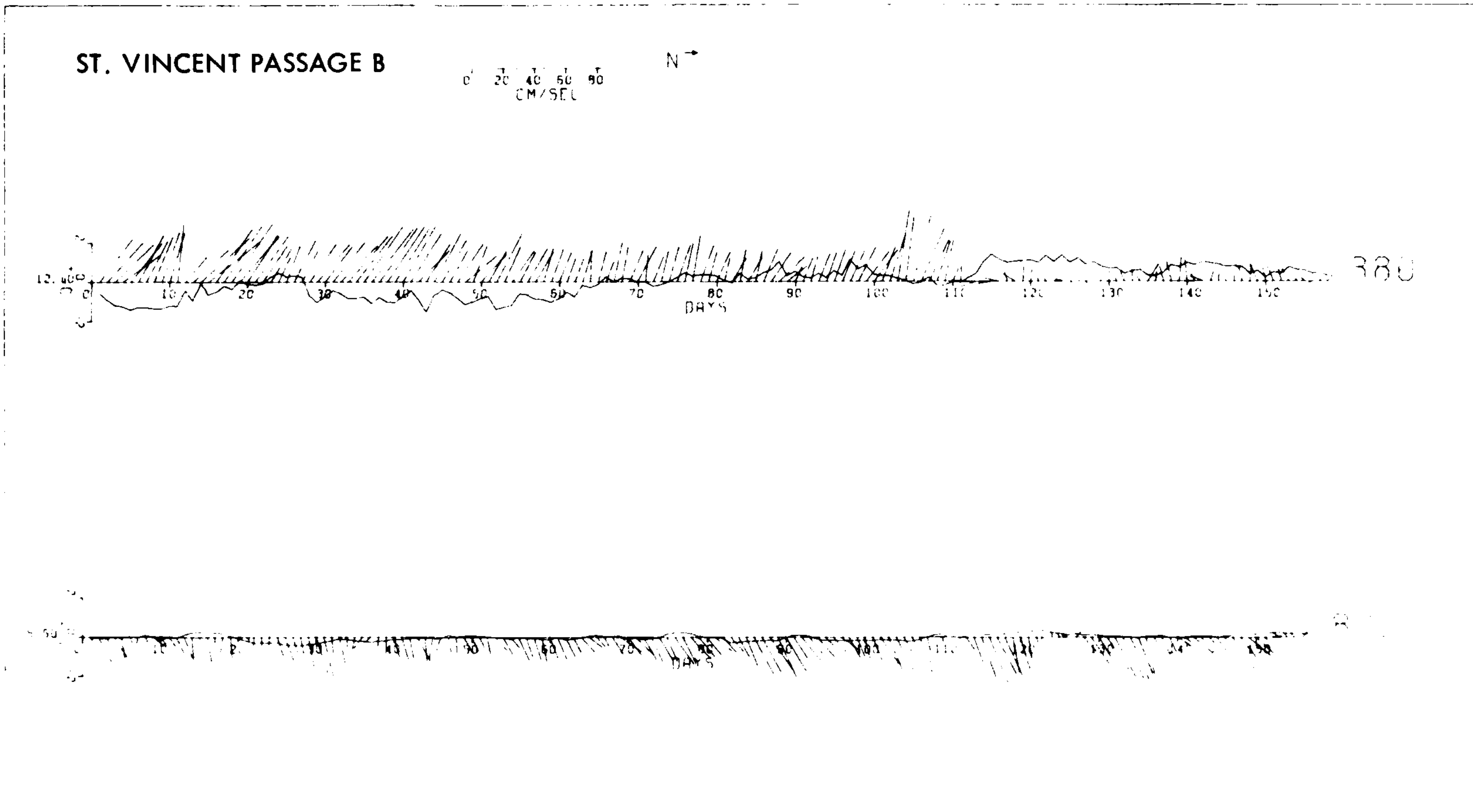

Figure 11. Daily vectors of flow and temperature (continuous line) from low-pass filtered data, St. Vincent Passage, array B (see Table 1). The number to the left of the temperature scale is the record mean.

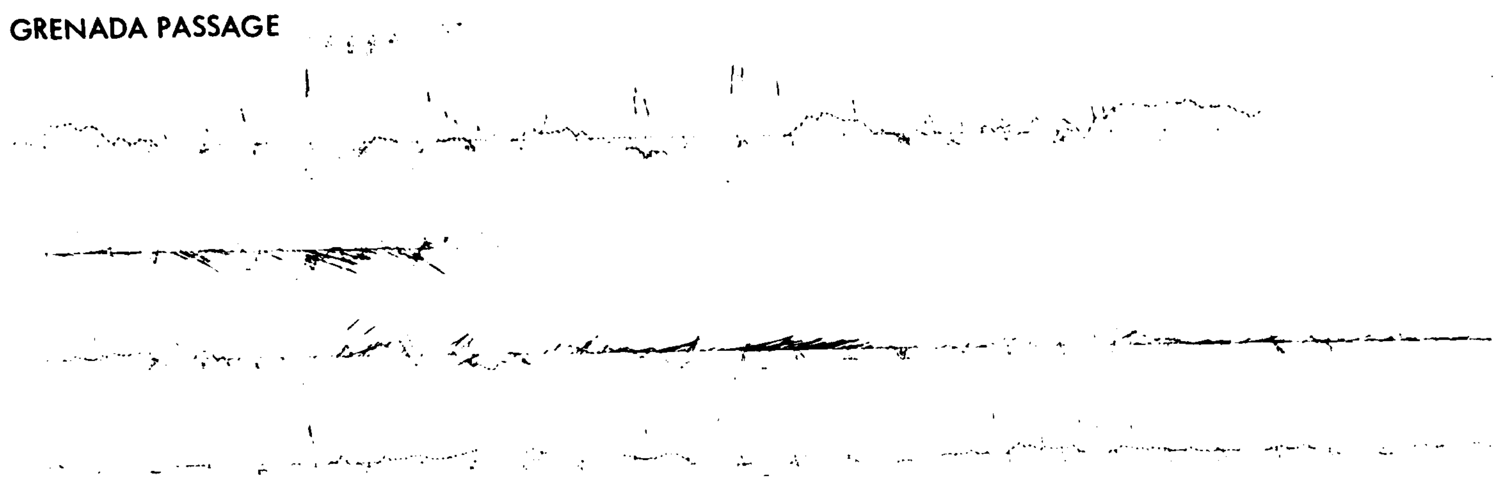

Figure 12. Daily vectors of flow and temperature (continuous line) from low-pass filtered data, Grenada Passage. The number to the left of the temperature scale is the record mean.

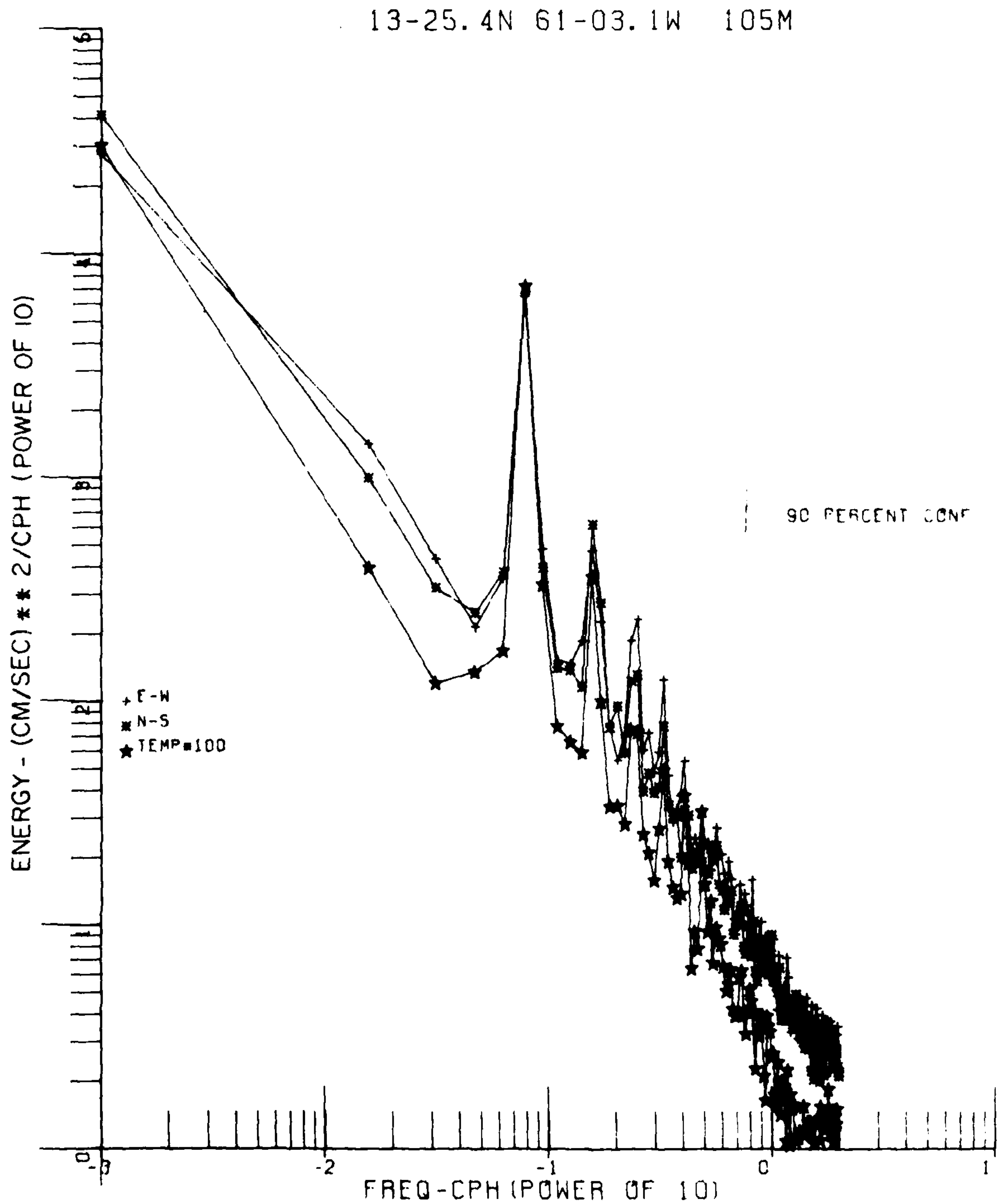

Figure 13. Variance spectra of flow components E (zonal) and N (meridional), and temperature (T^2/cph) at 105 m in St. Vincent Passage (array A, see Table 1). Data were not filtered.

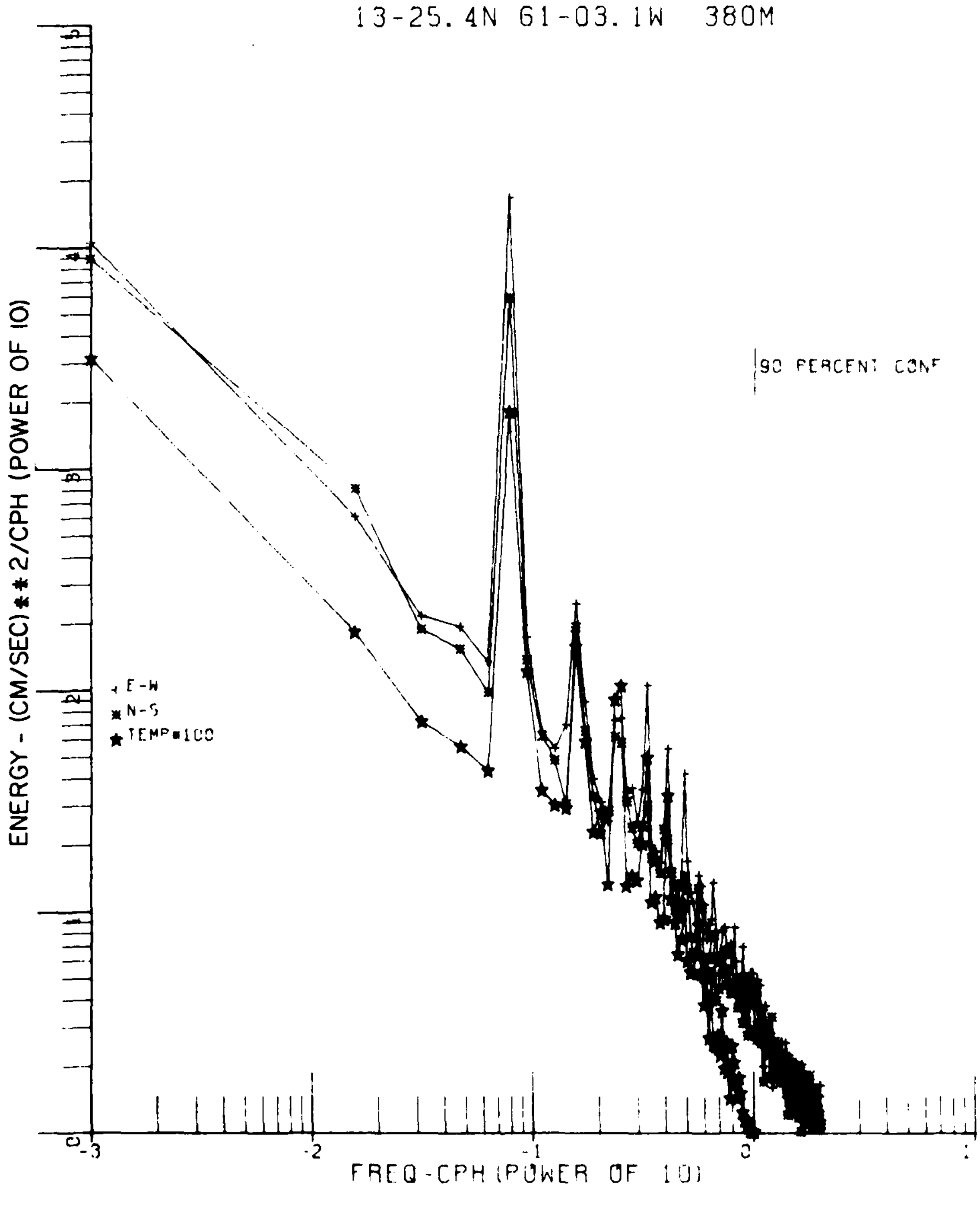

Figure 14. Variance spectra of flow components and temperature (T^2/cph), at 380 m in St. Vincent Passage (array A, see Table 1). Data were not filtered.

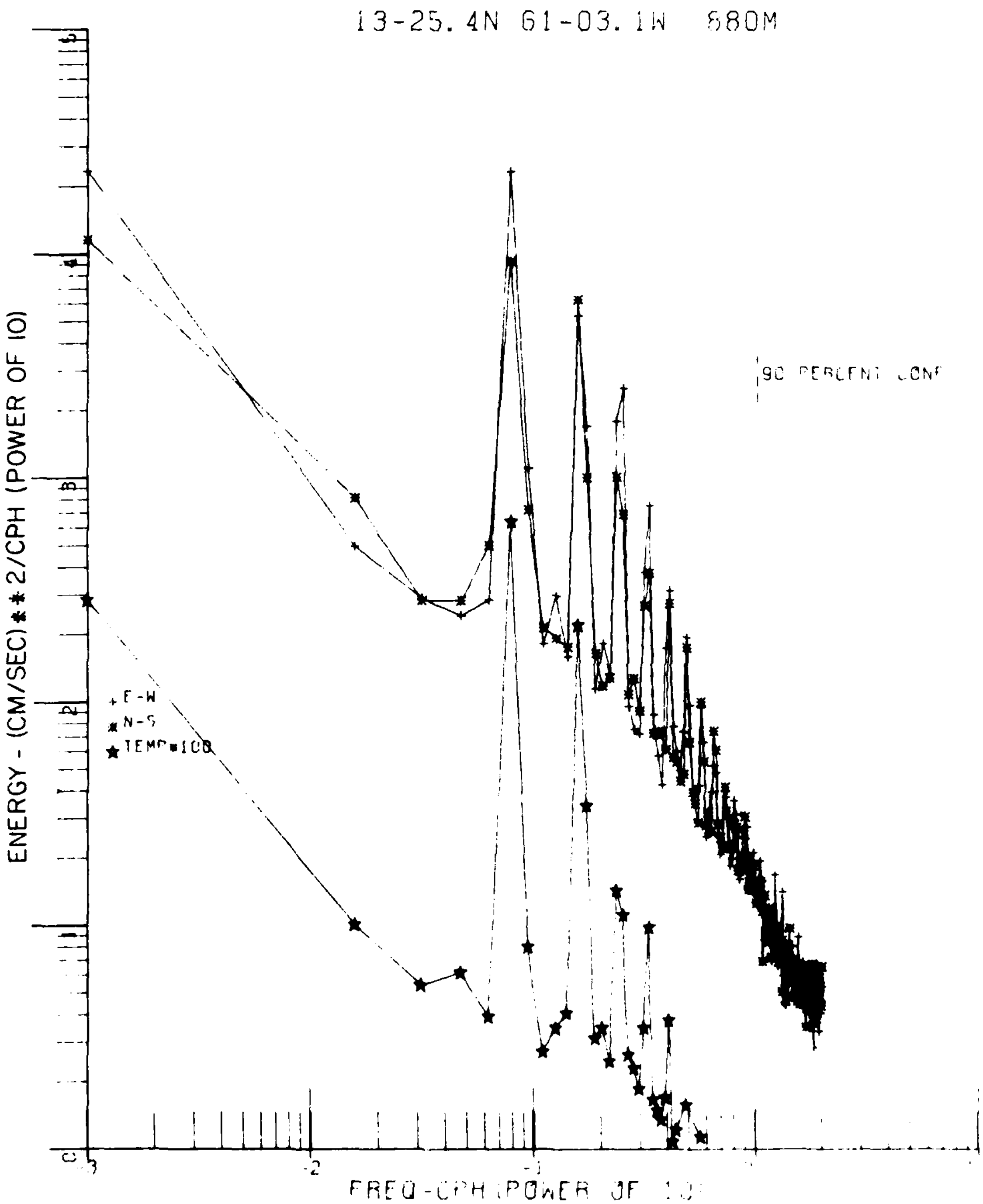

Figure 15. Variance spectra of flow components and temperature (T^2/cph) at 880 m in St. Vincent Passage (array A, see Table 1). Data were not filtered.

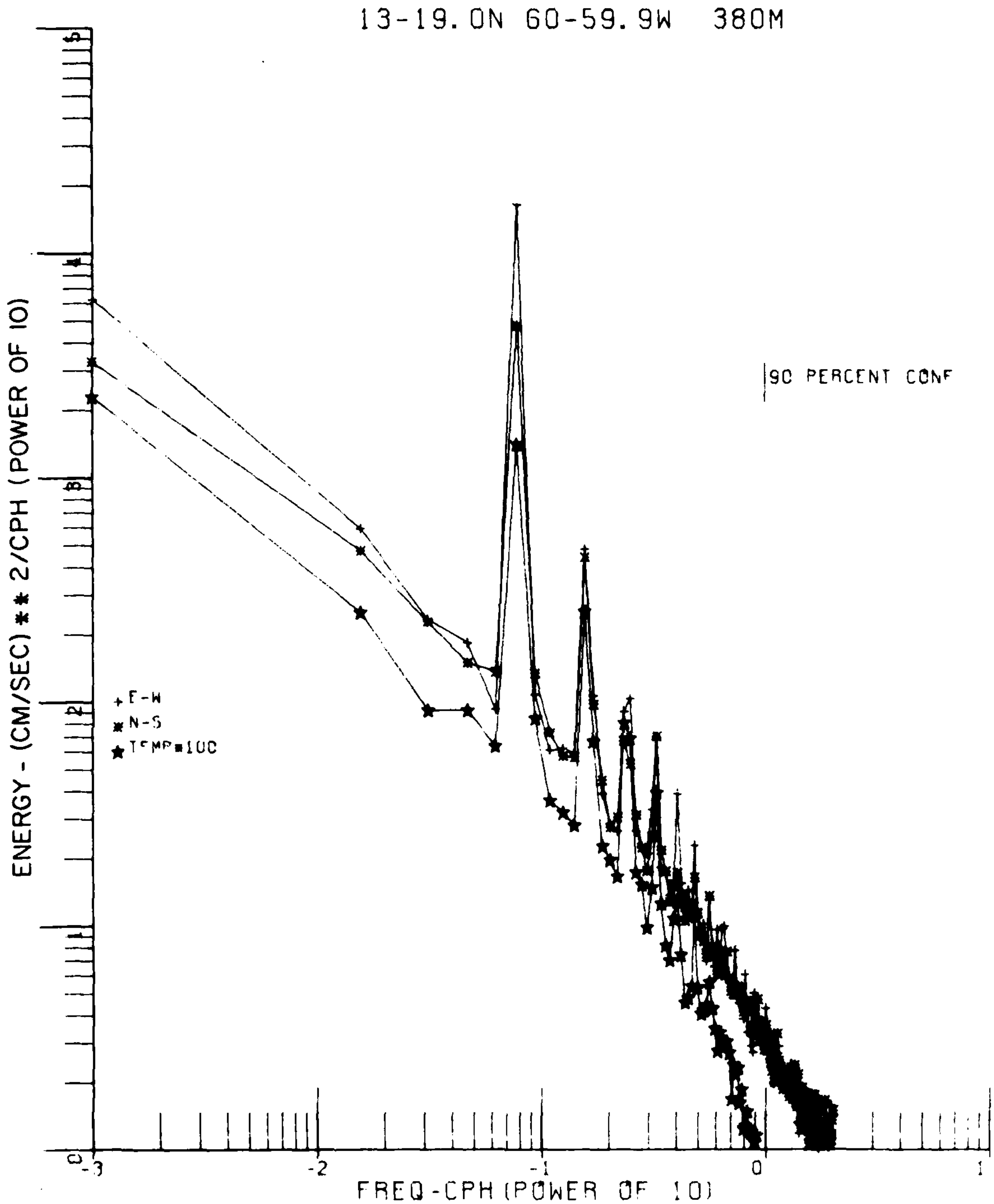

Figure 16. Variance spectra of flow components and temperature (T^2/cph) at 380 m in St. Vincent Passage (array B, see Table 1). Data were not filtered.

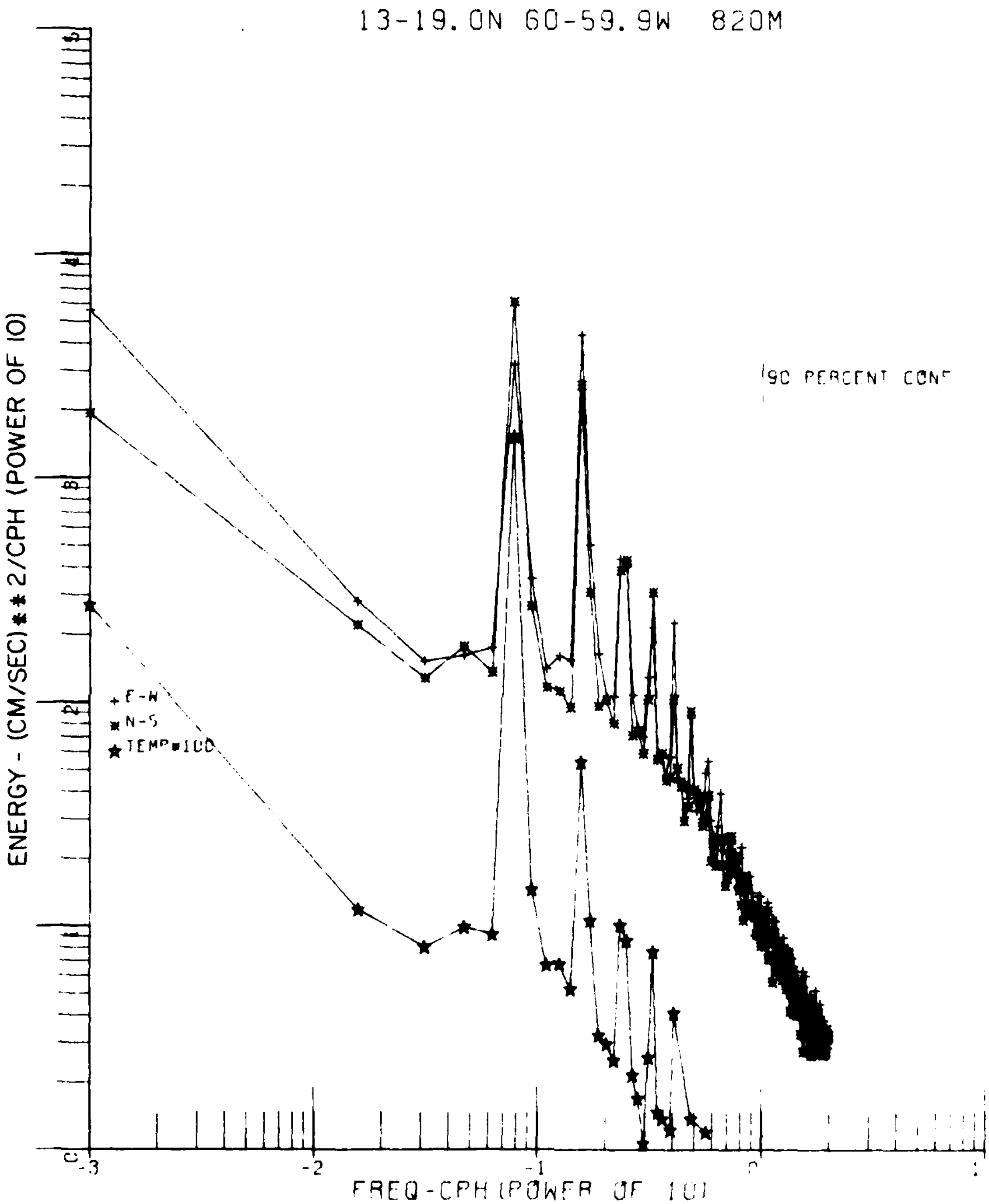

Figure 17. Variance spectra of flow components and temperature (T^2/cph) at 820 m in St. Vincent Passage (array B, see Table 1). Data were not filtered.

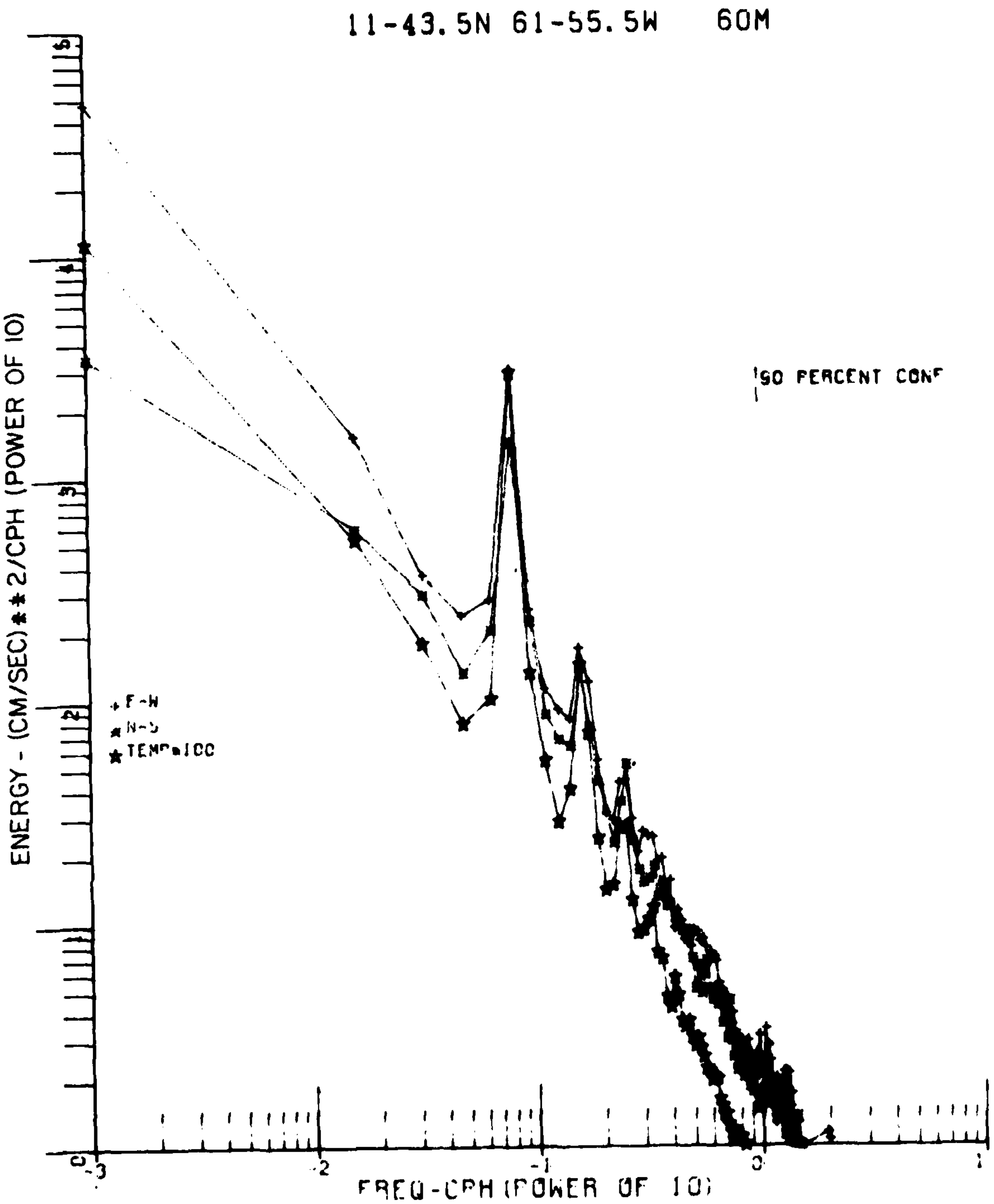

Figure 18. Variance spectra of flow components and temperature (T^2/cph) at 60 m in Grenada Passage (see Table 1). Data were not filtered.

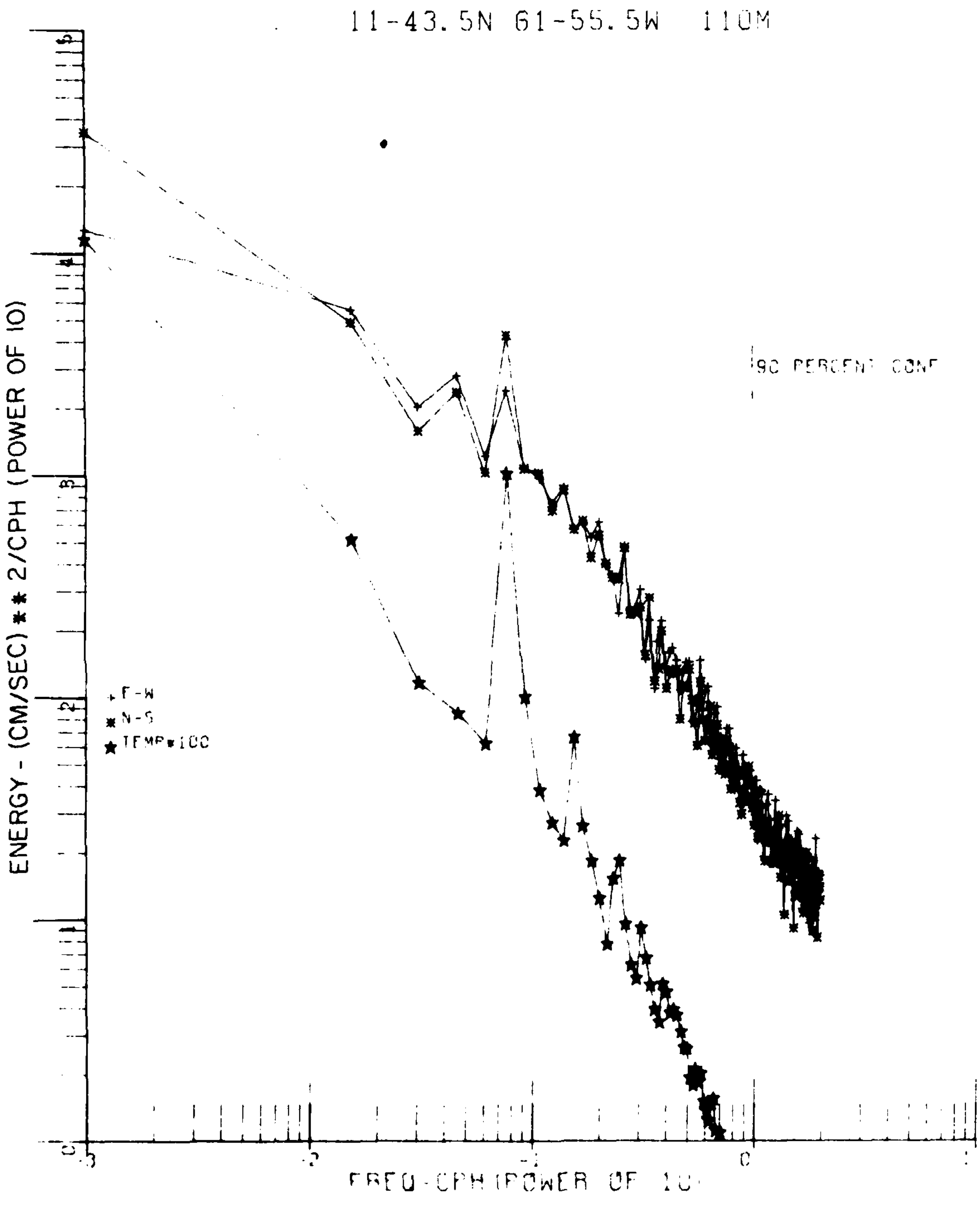

Figure 19. Variance spectra of flow components and temperature (T^2/cph) at 110 m in Grenada Passage (see Table 1). Data were not filtered.

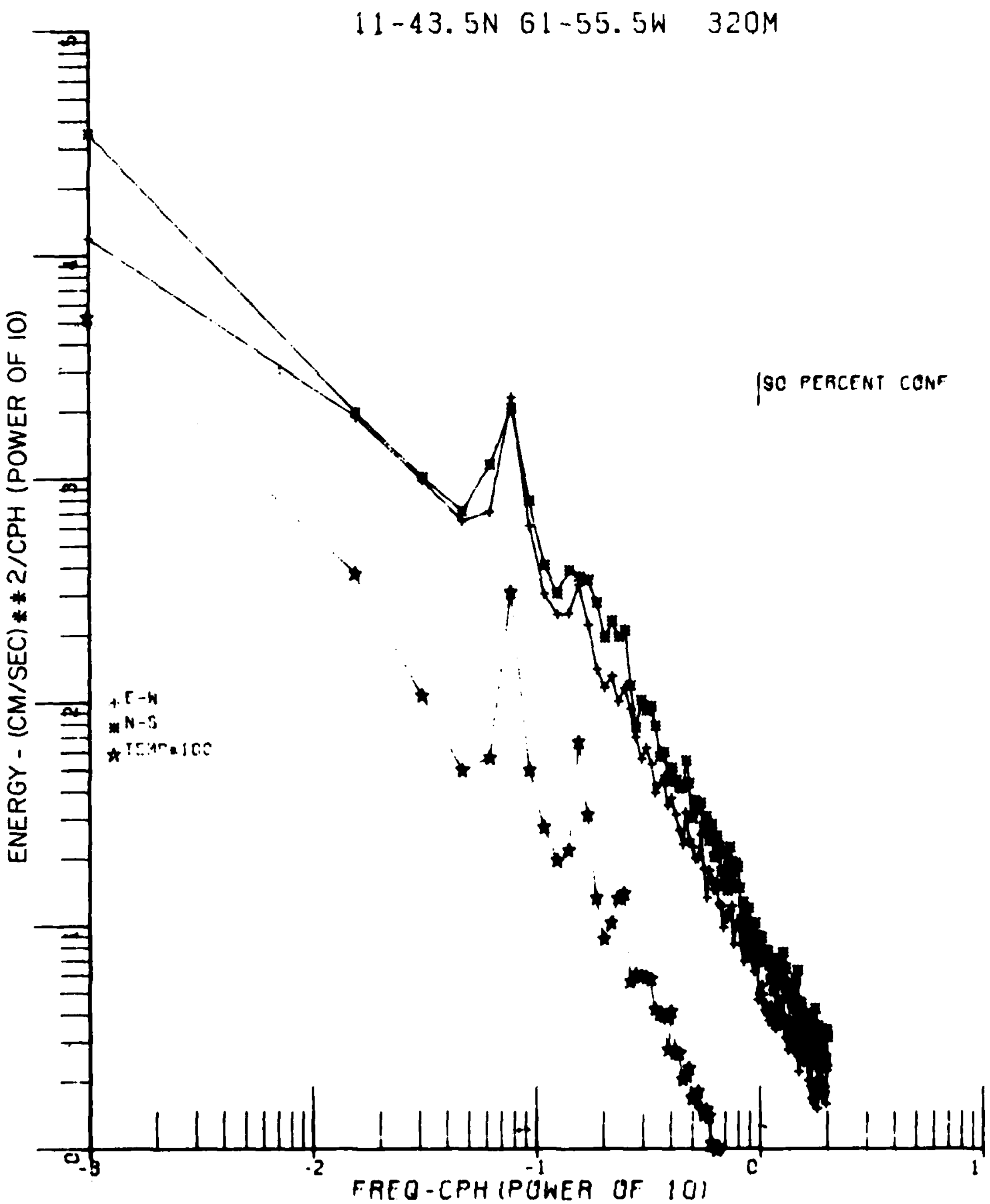

Figure 20. Variance spectra of flow components and temperature (T^2/cph) at 320 m in Grenada Passage (see Table 1). Data were not filtered.

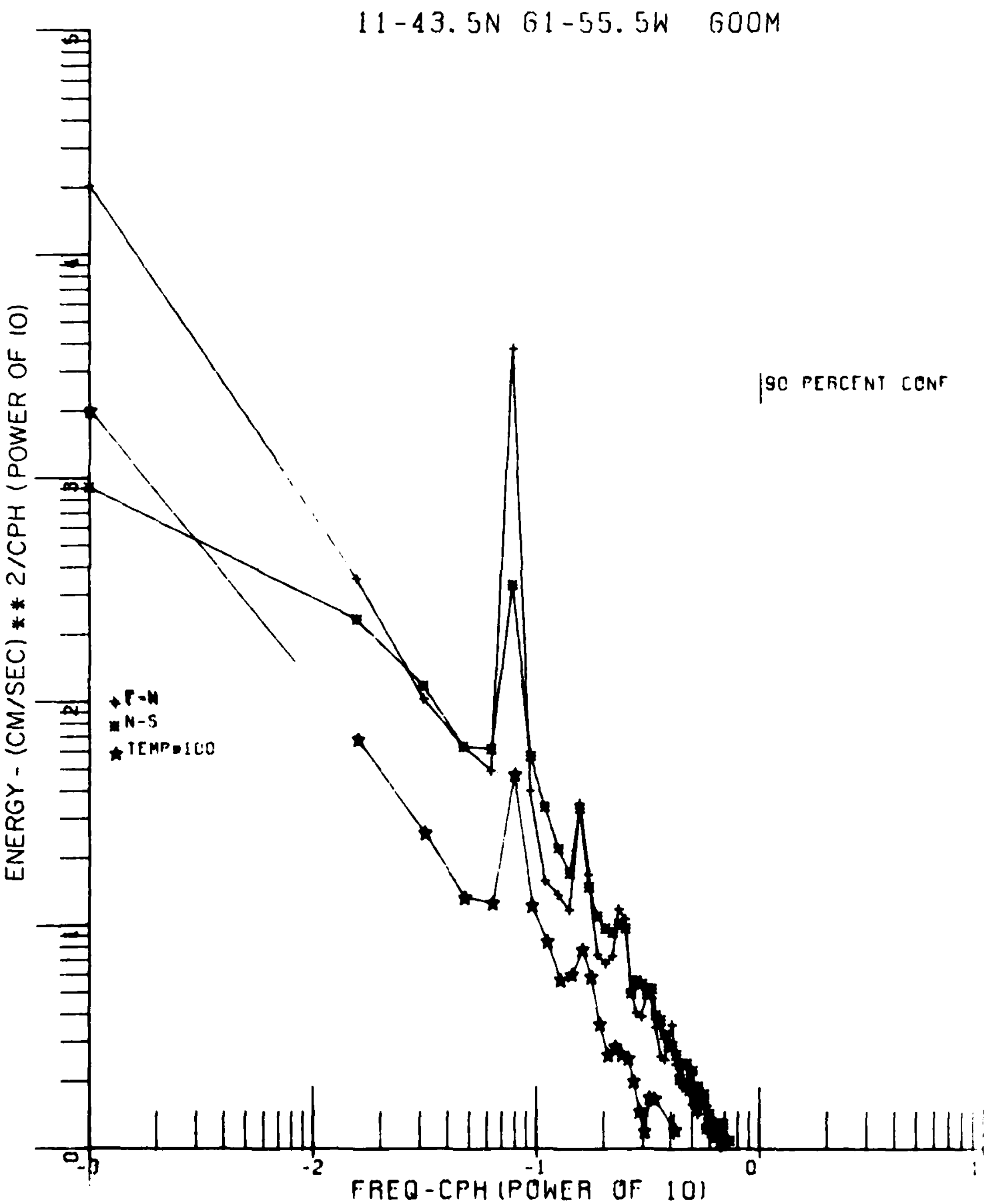

Figure 21. Variance spectra of flow components and temperature (T^2/cph) at in Grenada Passage (see Table 1). Data were not filtered

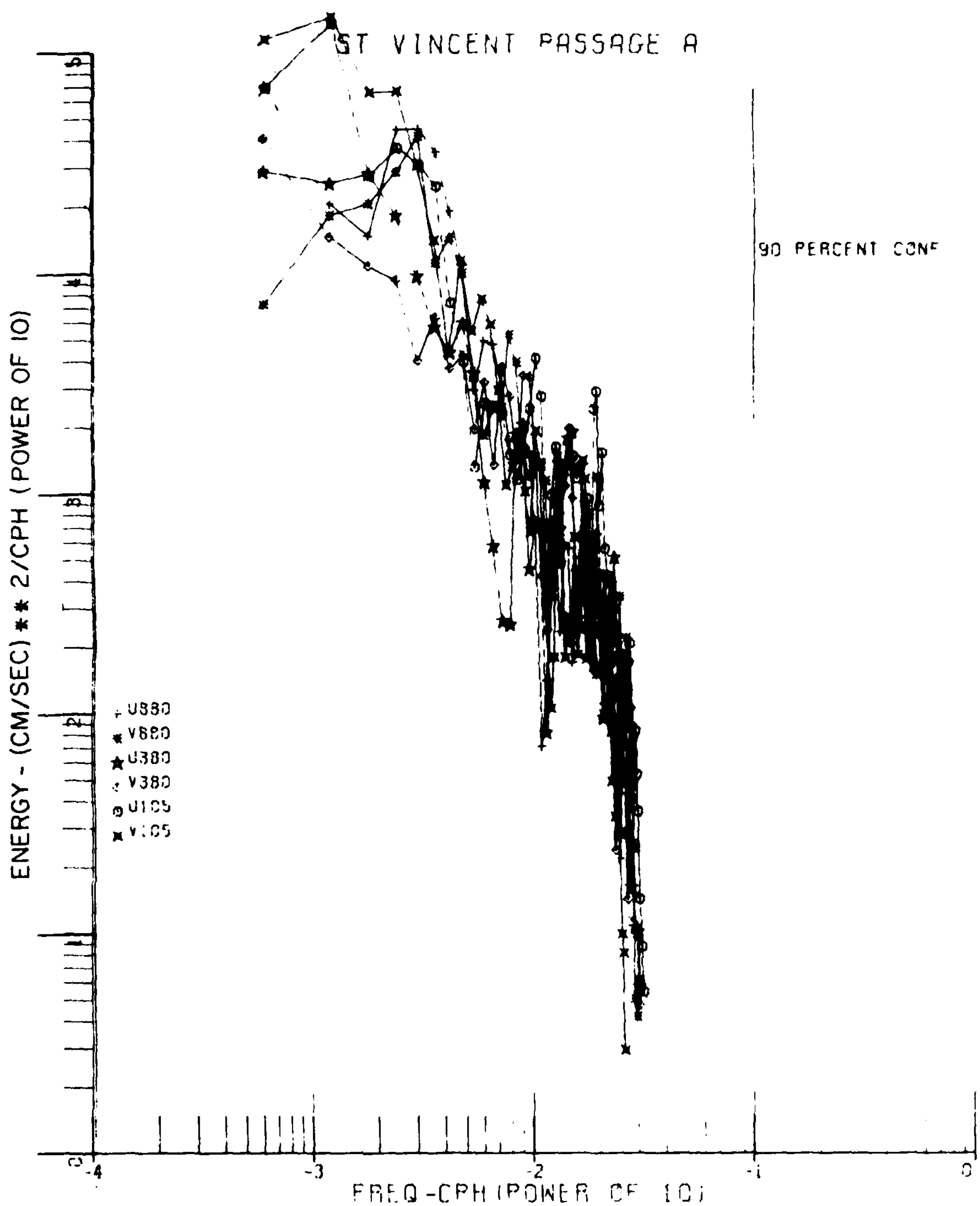

Figure 22. Low frequency variance spectra of E and N components at 105 m, 380 m, and 880 m in St. Vincent Passage (array A, see Table 1).

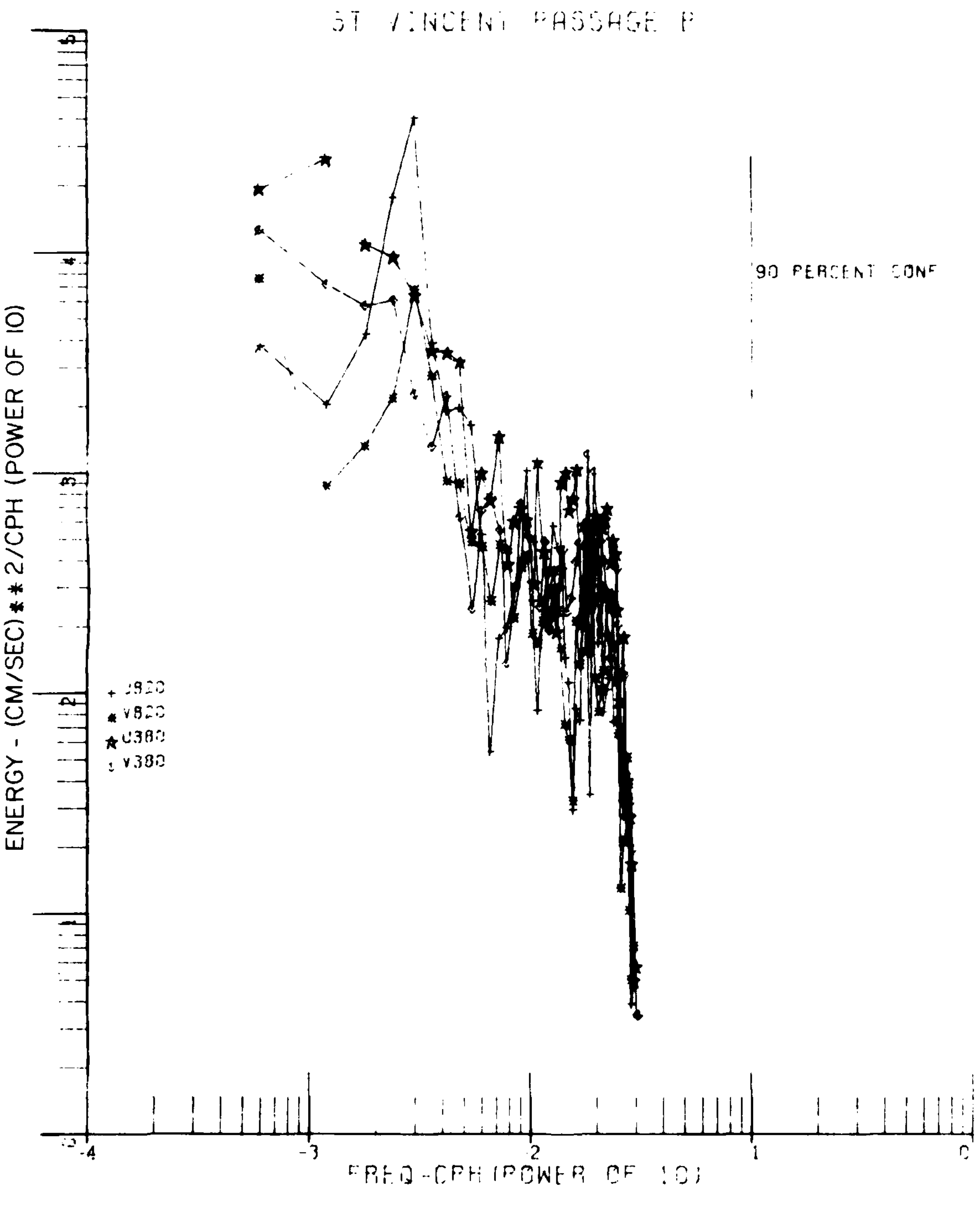

Figure 23. Low frequency variance spectra of E and N components at 380 m and 8?? m in St. Vincent Passage (array B, see Table 1).

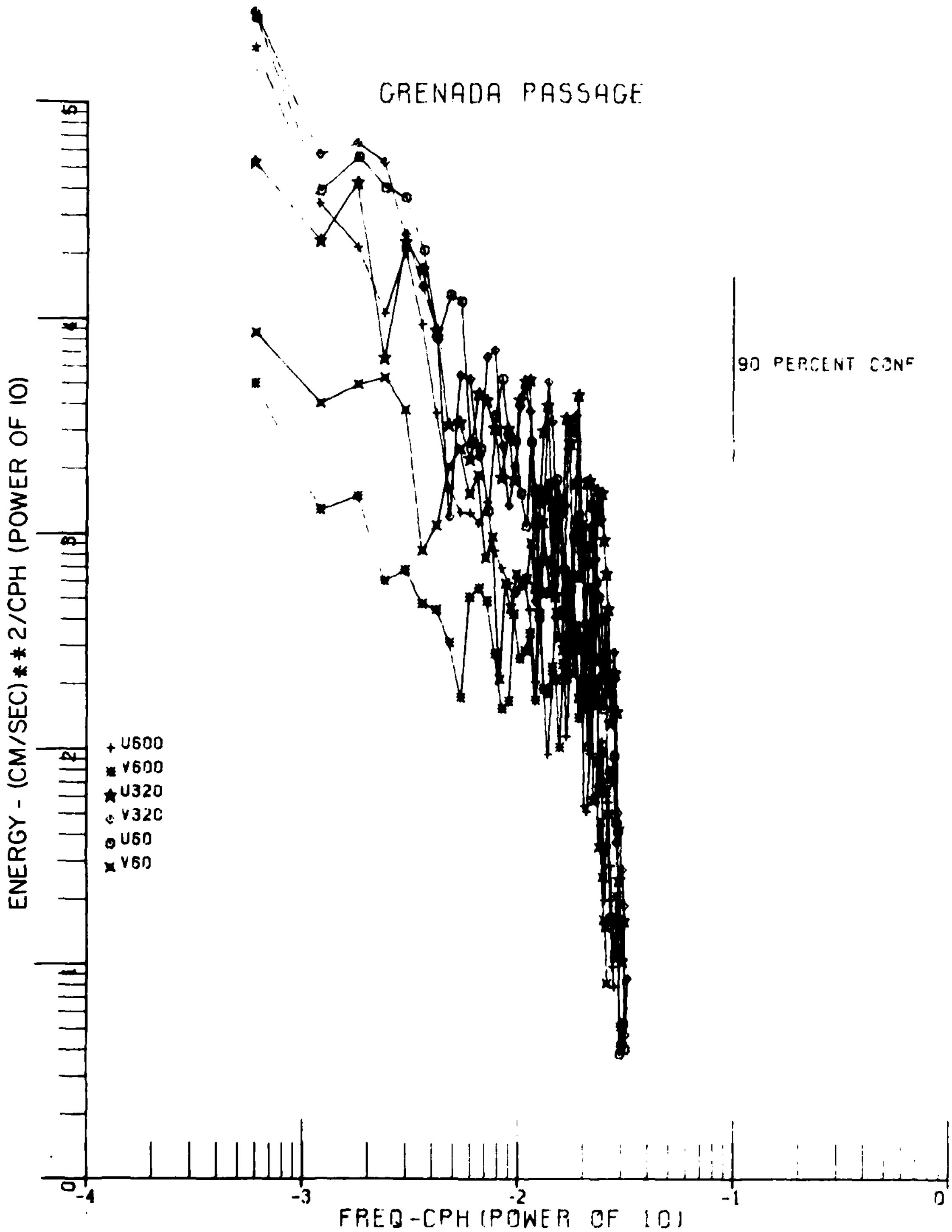

Figure 24. Low frequency variance spectra of E and N components at 60 m, 320 m, and 600 m in Grenada Passage (see Table 1).

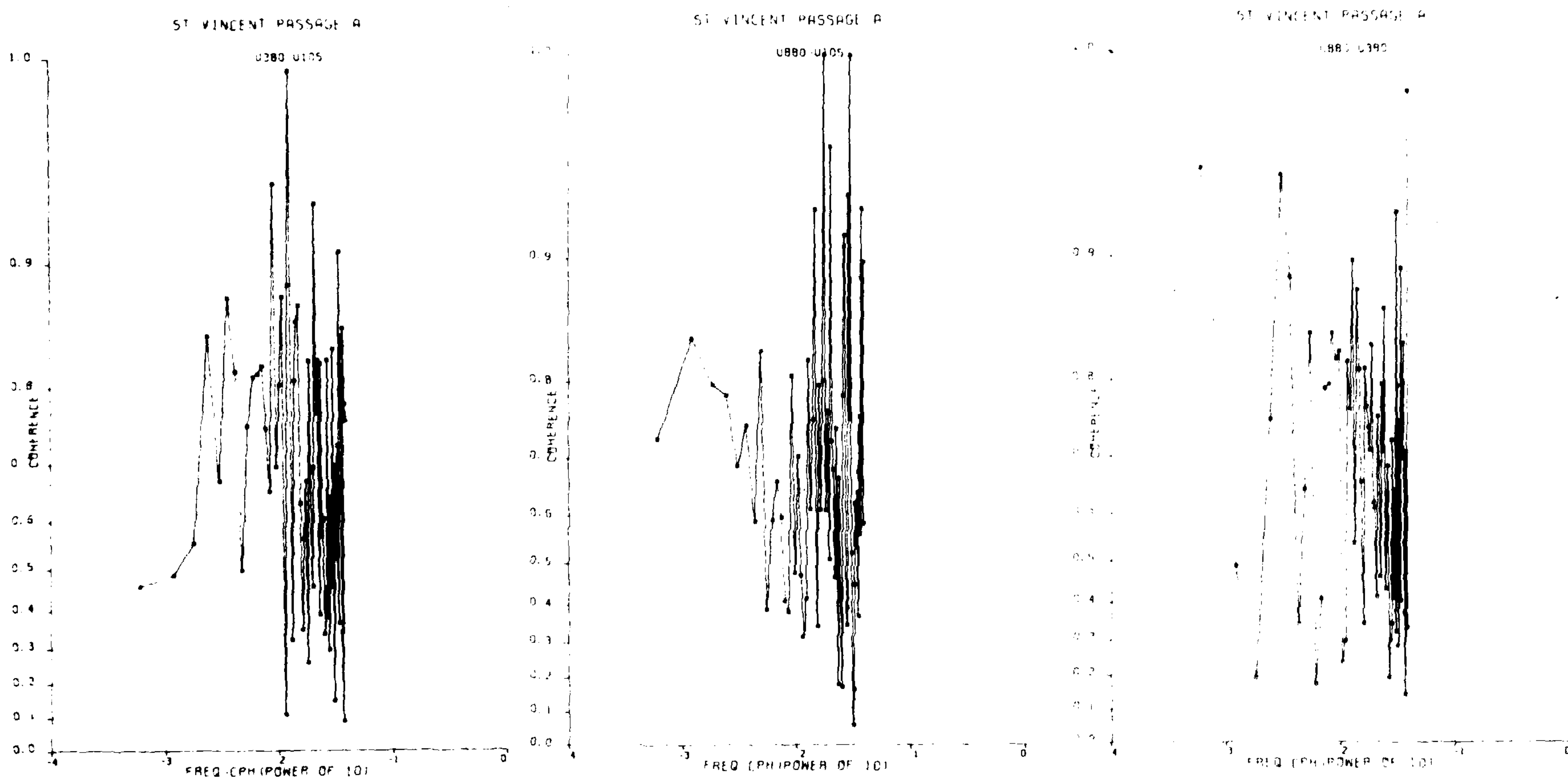

Figure 25. Coherence of E-W components of flow in St. Vincent Passage between depths of 105 m, 380 m, and 880 m (array A).

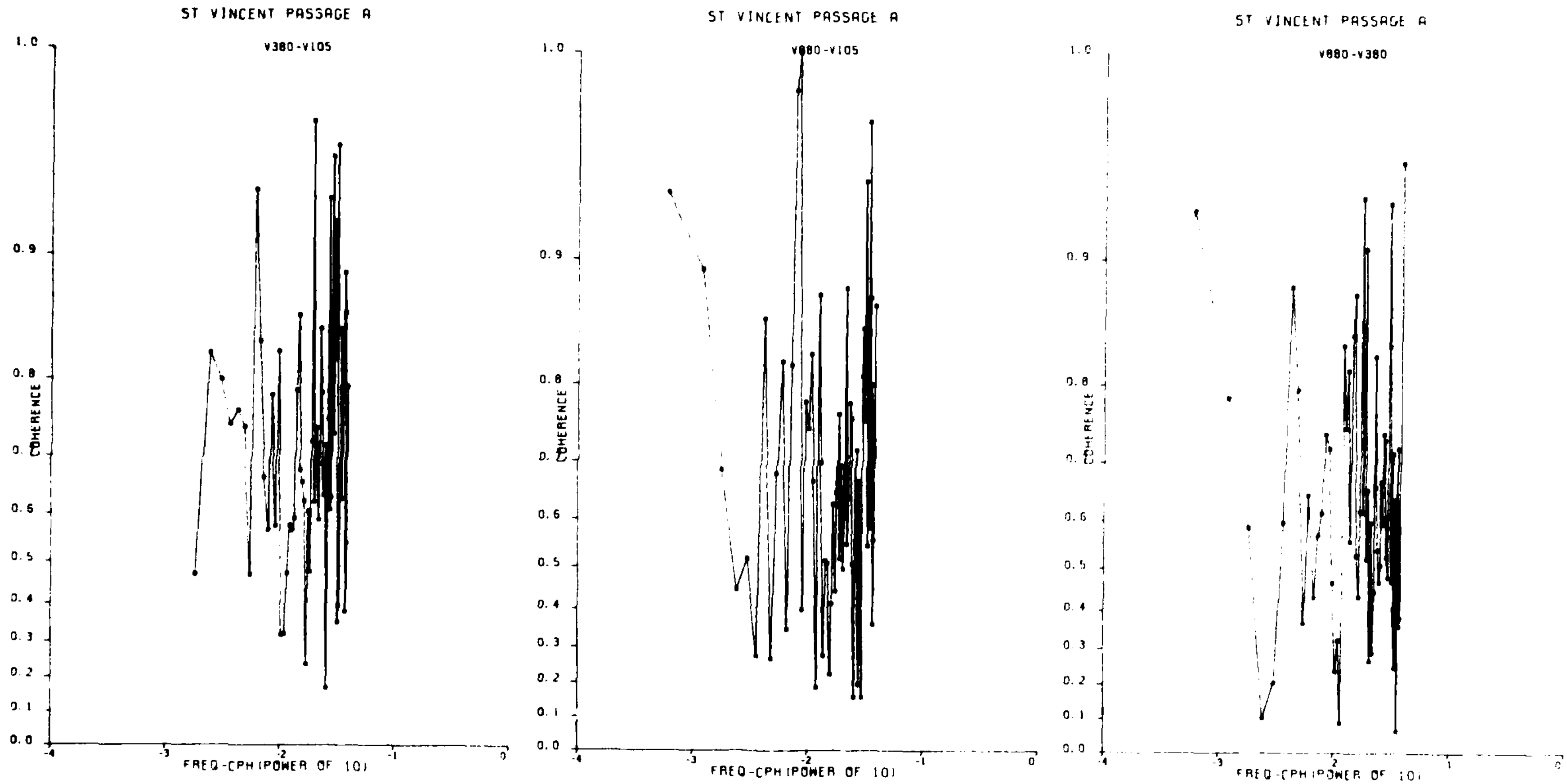

Figure 26. Coherence of N-S components of flow in St. Vincent passage between depths of 105 m, 380 m and 880 m (array A).

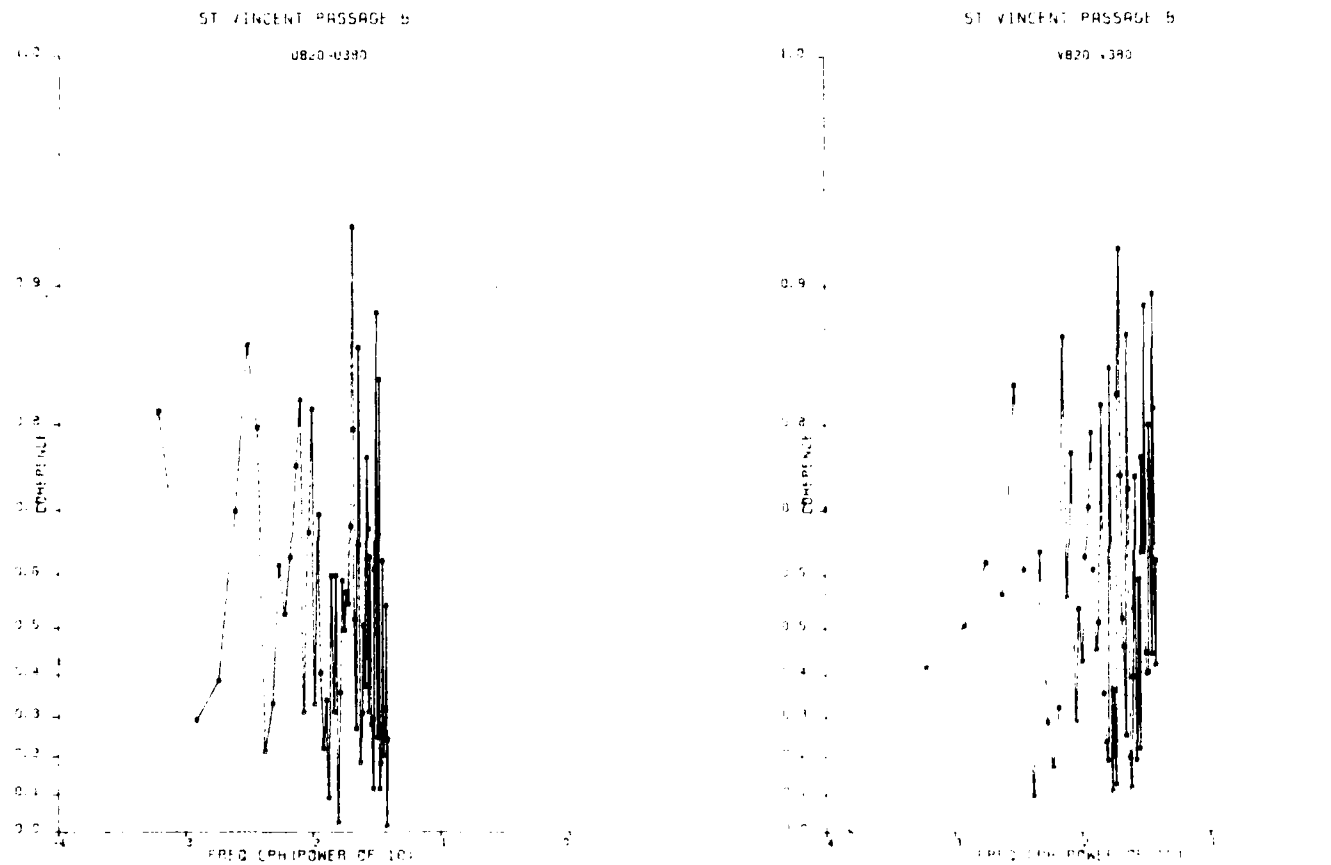

Figure 27. Coherence of E-W and N-S components of flow in St. Vincent Passage between depths of 380 m and 820 m (array B).

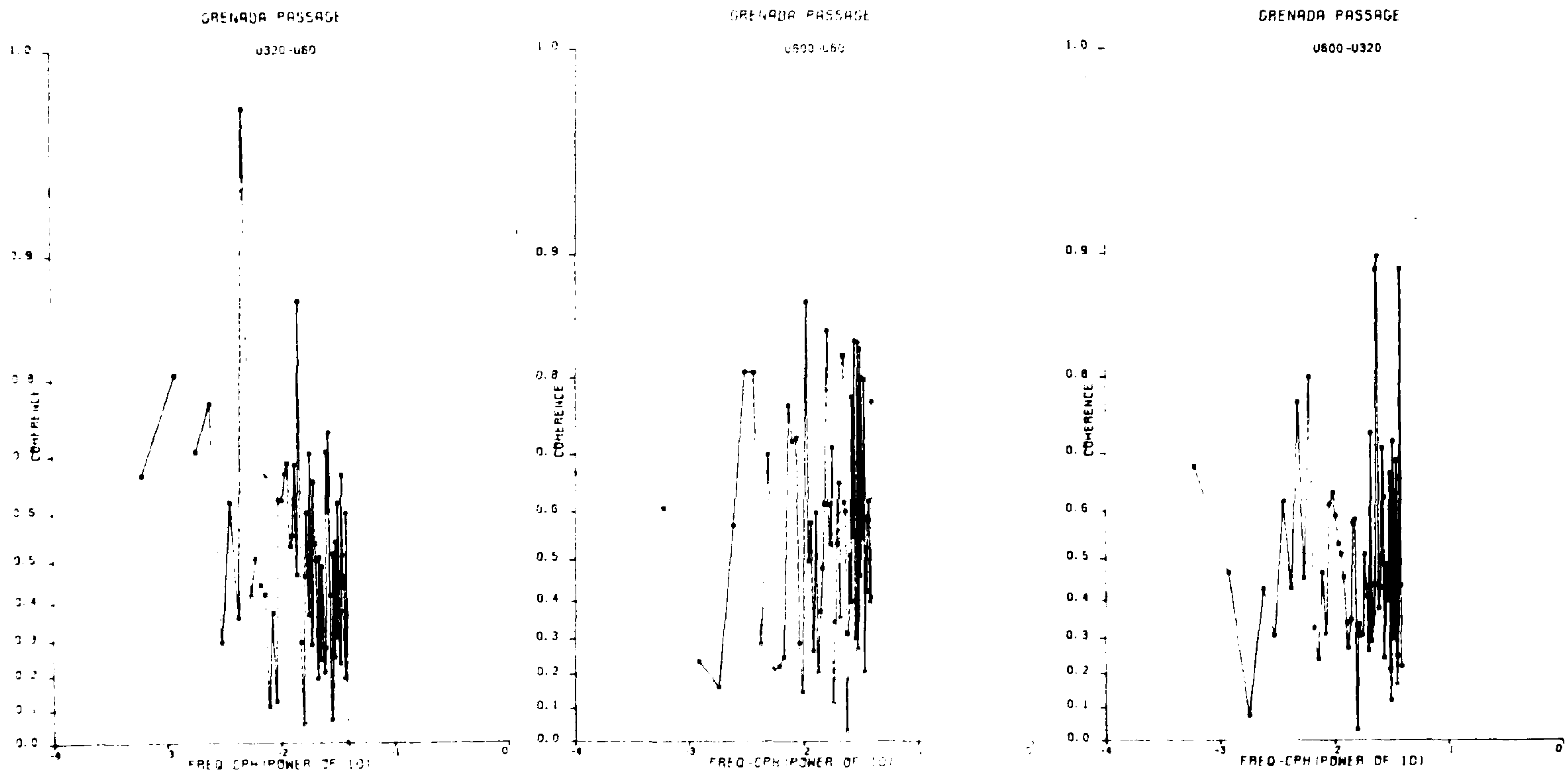

Figure 28. Coherence of E-W component of flow in Grenada Passage between depths of 60 m 320 m and 600 m.

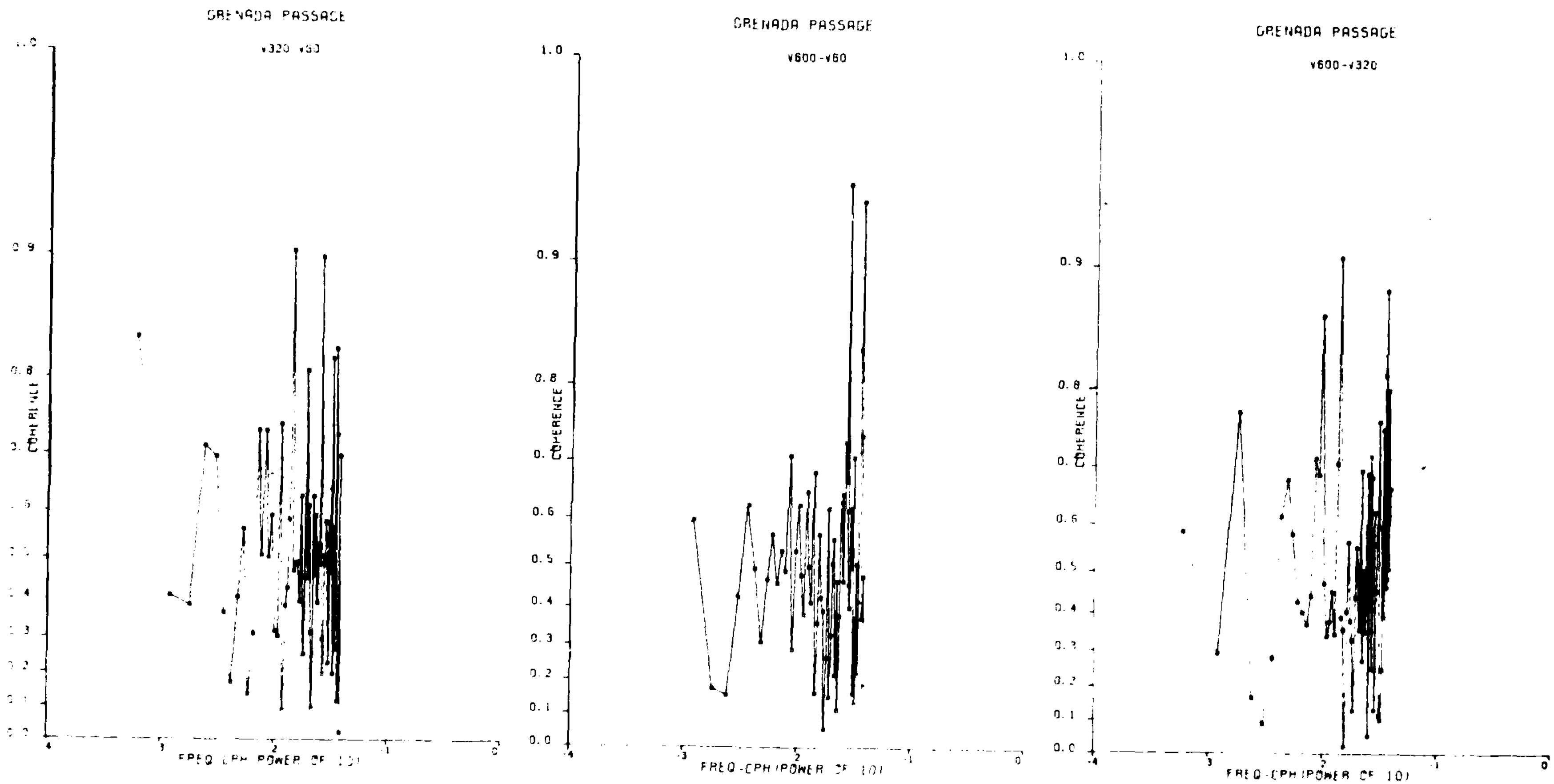

Figure 29. Coherence of N-S components of flow in Grenada Passage between depths of 60 m, 320 m and 600 m.

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		6. PERFORMING ORG. REPORT NUMBER
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Daily Vectors

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Between January and November 1977 flow was measured with ten current meters in St. Vincent and Grenada Passages. Mean scalar speeds exceeded 23 cm/sec at all instruments and flow was predominatly westward. Subinertial variability calculated using wide band (0.0156 CPH) spectral estimates was large, amounting to 14%-77% of the individual record variances. All records showed changes in low frequency flow, such as abrupt changes in direction, stagnation (period of low flow), or 360^{o} rotations in direction. Spectra

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showed peaks near 12-13 days in near-bottom records from St. Vincent passage, and peaks between 20 and 70 days in the other records.

Strong tidal signals were also found in the velocity records. Between 15% and 74% of the individual record variances were in diurnal, semidiurnal, or harmonic frequency bands. The semidiurnal frequency band contained from 11%-67% of the record variances. Tidal harmonics were also cleary evident, especially at the two near-bottom instruments deployed sequentially in St. Vincent Passage, where the first five harmonics of the semidiurnal frequency accounted for 27%-35% of the variance.

Each instrument recorded temperature, and most of the individual record variance was either subinertial (8%-86%) or semidiurnal (4%-82%). Together, these frequency bands accounted for 69% of the variance. Tidal harmonics accounted for 2%-25% of the temperature variance.

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